STATE OF CALIFORNIA
EDMUND G. BROWN
Governor

SUMMARY OF
MARINE WASTE DISPOSAL RESEARCH PROGRAM IN CALIFORNIA

1960

STATE WATER POLLUTION CONTROL BOARD
SACRAMENTO, CALIFORNIA
Publication No. 22

STATE OF CALIFORNIA

STATE WATER POLLUTION CONTROL BOARD

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Publication No. 22

THE ROYAL SOCIETY
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Founded 1876

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O.B., TRURO

STATE WATER POLLUTION CONTROL BOARD

RESEARCH CONSULTING BOARD

1 April 1960

California State Water
Pollution Control Board
1227 "O" Street
Sacramento 14, California

Gentlemen:

Transmitted herewith is a Summary Report on the Marine Waste Disposal Research Program in California. This report is submitted for your review and consideration in accordance with the contractual requirement that the Research Consulting Board shall advise and make recommendations to the State Water Pollution Control Board in the planning and execution of the Board's research program.

Specifically, it is the purpose of this report to describe the origin, nature, scope, aims, progress, significant findings, and future plans of the entire marine waste disposal research program in California. As such, the report brings together in one document a description of the several research programs of marine waste disposal being conducted under State sponsorship, and it attempts to show how these projects are interrelated in a broad assault on this relatively unknown area of research.

The report does not contain a chapter with summary and conclusions for two reasons: first, the report itself is a summary of the comprehensive progress reports submitted by each research contractor; and second, conclusions at this time would be premature inasmuch as most of the projects are still in progress. The final chapter, however, reviews the progress to date and points out the areas of research where further support and intensified effort are needed.

It has been an honor and a pleasure to serve in an advisory capacity to the State Board in this major research effort. We trust that this summary report will assist you in evaluating the program and that it will apprise water pollution control personnel throughout the State and elsewhere of the nature and scope of the research.

Respectfully submitted,

RESEARCH CONSULTING BOARD

Erman A. Pearson

Erman A. Pearson

Richard D. Pomeroy

Richard D. Pomeroy

Jack E. McKee

Jack E. McKee

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ACKNOWLEDGMENTS

This report is largely a summary of the research work of many investigators. As such, it has drawn on the data and scientific findings of each contracting group, as published in progress reports. Full credit for all of this research rests with the primary research workers. These individuals are listed in the appropriate chapters.

Sections of the report dealing with specific projects were submitted to the principal investigators for review, in order to correct errors of factual material. Their kind assistance in reviewing such chapters and in suggesting appropriate changes is deeply appreciated. The investigators do not, however, assume responsibility for all statements herein.

From time to time during the past three years, the Research Consulting Board has held meetings at which engineering and scientific personnel of the contracting agencies have presented brief descriptions of their work and current findings. These meetings were attended by representatives of state departments, city and county government, federal agencies, universities and colleges, research institutes, industry and industrial associations, and private business. Each participant was invited to ask questions or to contribute to the discussion. We acknowledge with thanks the many suggestions and recommendations from these participants and we appreciate their interest in the program. Indeed, one industrial group, the Western Oil and Gas Association, augmented their interest in the program by providing funds for the project dealing with oil on the beaches.

Numerous individuals have assisted this research work by their personal interest and by their constructive suggestions to the Research Consulting Board or directly to the contracting groups. We hesitate to list them by name for fear that many would be omitted inadvertently inasmuch as their assistance has been largely anonymous and informal. To all of them, we express our deepest appreciation.

Individual members of the state and regional water pollution control boards, their executive officers, and staff engineers have been most helpful in providing guidance for specific projects and suggestions for the overall program. We are particularly indebted to the Executive Officer of the State Water Pollution Control Board, Mr. Paul R. Bonderson, and to his staff for their wholehearted cooperation and assistance. We trust that the results to date have justified their enthusiasm and support.

CHAPTER I

INTRODUCTION

One of the distinguishing characteristics of western civilization is the development of environmental sanitation. The cornerstone of sanitation is the water-carriage system of waste disposal. Utilizing the hydraulic principles of buoyancy and scour, systems of plumbing and sewerage convey domestic and industrial wastes from homes and factories to a location, preferably remote, where they can be disposed of readily, without offense and without harm to the public health or welfare. Owing to the chemical, physical, and biological nature of water-borne wastes, it has been convenient to discharge them into surface waters for subsequent dilution and biochemical stabilization. While land disposal, ground-water recharge, and reclamation or reutilization are being practiced in many localities, the overwhelming bulk of liquid wastes, municipal and industrial, are discharged to surface water courses.

Prior to the "Great Sanitary Awakening" at the turn of the twentieth century, the condition of the receiving waters was generally ignored, except for offensive odors. With the advent of sanitary engineering, however, the epidemiological hazards of contaminated water were recognized and effective action was taken to reduce the pollution of surface waters. Quite logically, attention was directed first, and almost exclusively, to fresh-water streams and lakes, for they were commonly the sources of municipal water supply. Moreover, fresh waters were frequently so limited in volume or flow that the presence of liquid wastes depressed the oxygen content, caused discoloration and turbidity, killed fish, or otherwise produced dramatic effects. Salt water in the open ocean or brackish water in tidal estuaries received scant attention, for the discharge of wastes into such waters appeared to have little, if any, effect on their subsequent uses.

It is not surprising, therefore, that sanitary engineers and related scientists amassed during the past half century a wealth of information and experience pertaining to the effects of domestic and industrial wastes on fresh-water streams and lakes. It is equally not surprising that very little knowledge was accumulated relative to the import of waste disposal in the marine environment. This disparity is evident from the literature survey described in *Water Quality Criteria* (Publication No. 3, California State Water Pollution Control Board). Literature relative to the effects of specific pollutants on the beneficial uses of fresh water, especially aquatic life, is prolific; but prior to 1950 literature on man-made pollution of the marine environment was relatively limited. Yet, much of the nation's wastes are discharged into saline waters.

MARINE WASTE DISPOSAL IN CALIFORNIA

Population and industry in California have tended to concentrate in coastal communities, with the result that approximately two-thirds of the municipal and industrial water-borne wastes are discharged to saline waters. Indeed, more than 125 California communities dispose of their sewage effluent, after varying degrees of treatment, through submarine outfalls. The location of major outfalls is shown on Figure 1. With the spread of suburban areas, the development of metropolitan districts, and the extension of trunk sewers farther inland, the magnitude of marine waste disposal in California is expected to increase markedly in the next few decades.

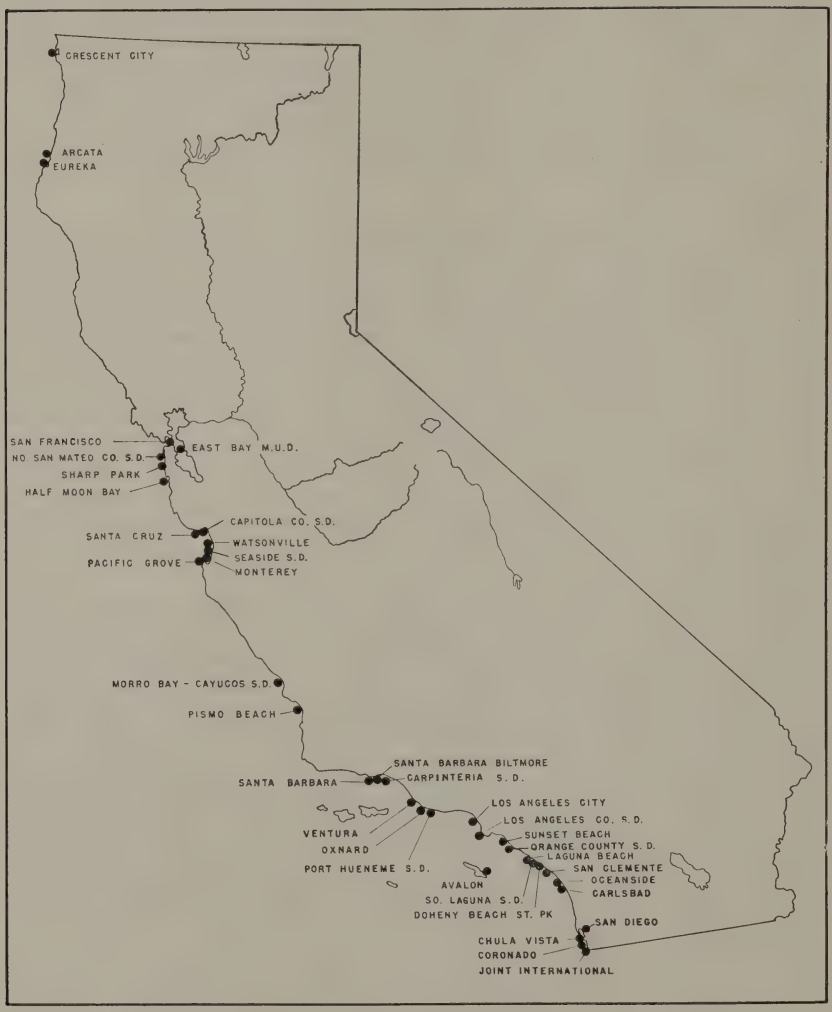


Figure 1
MAJOR SUBMARINE OUTFALLS IN CALIFORNIA

The magnitude and complexity of waste disposal to the marine environment in California are intensified by the nature and extent of beneficial uses of the saline receiving waters. In colder climates, many beneficial uses are limited by short seasons or restricted by rugged topography. The near-shore marine waters of California, however, are utilized extensively throughout the year, especially in southern California.

The beneficial uses of marine waters in California include swimming, surf bathing, beach picnicking, skin diving, industrial water supply, esthetic enjoyment, boating, propagation of fish and other aquatic life, sport fishing, commercial fishing, and propagation of kelp. The relative importance of these beneficial uses varies with season, with locality, and with the viewpoint of the user. Marine waters also serve as effective means for the dilution, dispersion, transport, and stabilization of partially treated water-borne wastes, without having an adverse affect upon the beneficial uses made of receiving waters, thus obviating the need for biological secondary treatment. In this fashion, marine waters provide an asset to contiguous communities, a use that cannot be ignored as a benefit to coastal cities.

CONTROL OF MARINE POLLUTION

It is the statutory duty of the water pollution control boards to protect the beneficial uses of all receiving waters, saline as well as fresh, from the adverse and unreasonable effects of waste discharges. With respect to any existing or planned discharge, the board having jurisdiction pursues a logical sequence of action, somewhat as follows:

1. The beneficial uses to be protected within specific areas are determined.

2. The potential effects of the waste and its constituents on each beneficial use are evaluated.

3. Requirements are established to limit the strength and quantity of specific pollutants in a waste discharge or in the receiving water so that beneficial uses are not impaired.

4. Compliance with the requirements is assured by a monitoring program involving physical, chemical, bacteriological, biological, and/or radiological analyses of the receiving waters as well as the discharged effluent.

The only uncertain step in the foregoing sequence is the delineation of the potential effects of the waste and its constituents, at various degrees of dilution, on the beneficial uses of the marine environment. Here, the board will be guided by the recommendations of the State Department of Public Health, the State Department of Fish and Game, the State Department of Water Resources, the U. S. Corps of Engineers, and other agencies having primary interest in the quality of receiving waters. Yet, there are many potentially polluting substances for which threshold and limiting concentrations for specific beneficial uses are not known and not established. Indeed, the only criterion of saline water that has acquired the status of a rigid standard in California is the concentration coliform bacteria in areas of water-contact sports. The limiting value has been set by the State

Department of Public Health at 10 per milliliter, not to be exceeded in more than 20% of the samples at a given location within a specified period of time. Failure to comply with this standard may result in quarantine of the beaches and nearshore waters.

INITIAL PHASES OF RESEARCH

Cognizant of the dearth of quantitative scientific data on the effects of municipal and industrial wastes in the marine environment, and recognizing the need for such information to enable the regional boards to prescribe waste discharge requirements and to establish monitoring programs of receiving waters, the State Water Pollution Control Board contracted with Dr. Erman A. Pearson of the University of California at Berkeley on 1 July 1954 for an exploratory investigation of all aspects of the submarine outfall disposal of domestic water-borne wastes. In so doing, the State Board was complying with its statutory function to administer programs of applied research in the technical phases of water pollution control. The specific aims of Dr. Pearson's investigation were to accumulate, analyze, interpret, and evaluate all literature, data, information and experience pertaining to submarine outfalls, to summarize the existing state of knowledge of this subject, and to recommend programs for future projects to fill in the gaps of present information.

Dr. Pearson's report, submitted in December 1955, has been printed and distributed widely as SWPCB Publication No. 14 "An Investigation of the Efficacy of Submarine Outfall Disposal of Sewage and Sludge". Chapter XIII of this report presented the following eight recommendations for additional programs of research investigation:

1. Development of methodology and equipment for adequate monitoring and resolution of the circulation system in near-shore waters adjacent to submarine outfalls, especially with respect to horizontal and vertical velocity characteristics.

2. Fundamental analysis of the characteristics of mixing and dispersion of sewage in sea water, first with respect to the initial gravitational diffusion and second with the horizontal and vertical dispersion after initial mixing.

3. Studies on the viability of enteric bacteria in sea water, including reaction kinetics, effects of adsorption and sedimentation, and improvement of analytical techniques.

4. Evaluation of specific aspects of the submarine outfall disposal of digested sludge.

5. A critical review and analysis of bathing-water criteria and evaluation programs.

6. Studies relating to the biological evaluation of receiving waters, with the intent of developing simple, semi-quantitative indices of adverse biological effects.

7. Analysis of the effect of wind and wind waves on the dispersion of sewage-sea water mixtures.

8. Investigation of the factors affecting the stability of submarine pipelines, especially with respect to littoral drift of sediments and the effect of waves and swell.

On the basis of Dr. Pearson's recommendations, the State WPC Board decided in 1956 to concentrate its major research efforts on specific aspects of waste disposal in the marine environment. As the first step in this direction, the State Board in September 1956 authorized a contract with the University of Southern California, utilizing the facilities of the Allan Hancock Foundation for Scientific Research, to conduct an oceanographic survey to determine the natural environmental characteristics of the continental shelf area of southern California and to gather data to reveal changes in the marine environment in vicinities of existing outfalls. (See Chapter III.)

APPOINTMENT OF RESEARCH CONSULTING BOARD

Owing to the scientific and technical nature of submarine outfall research, and the desirability of following in detail the progress of such research, the State Board adopted a resolution on 7 November 1956 authorizing the employment of a board of consultants to aid in the planning and execution of the research program. This board, comprising Erman A. Pearson, Sc. D., as chairman, Richard D. Pomeroy, Ph. D., and Jack E. McKee, Sc. D., was officially activated on 11 January 1957. At that time, the only sponsored research project relating to the marine environment was the one started a few months previously by the Hancock Foundation. Subsequently, however, the research program was expanded to embrace all of the projects described in this progress report.

The consulting board's contract with the State WPC Board states that they shall "advise and make recommendations to the State Water Pollution Control Board in the planning and execution of the Board's research program for the purpose of assuring, to the maximum extent possible, that:

1. The scientific and technical data obtained from the submarine outfall research investigations can be interpreted and evaluated by water pollution control authorities;

2. The results of said research will be readily applicable to the practice of ocean outfall disposal of wastes; and

3. All phases of the submarine outfall research program be properly coordinated."

PURPOSE OF THIS PROGRESS REPORT

While the submarine outfall research program and investigations of numerous facets of waste disposal in the marine environment have been under the control of the State Water Pollution Control Board, and its Executive Officer, Paul R. Bonderson, the research consulting board has maintained close contact with the technical and scientific details of the several research projects so as to be able to submit advice and recommendations to the State Board. This close liaison has been effected by frequent visits to the laboratories of the contracting agencies and by conferences with the scientific and administrative personnel. An important function, however, has been review of the progress reports to assure that the results of the research are expressed in a form that can be utilized by water pollution control authorities. Finally, a series of research conferences or symposia have been held to enable

each contractor to learn of the work being performed by other groups. Foremost among these meetings was the "First International Conference on Waste Disposal in the Marine Environment", held at Berkeley, California, on 22-25 July 1959 under the joint primary sponsorship of the State Water Pollution Control Board and the University of California. This conference was attended by over 300 engineers and scientists from 13 countries.

These conferences, staff meetings, and detailed scientific progress reports serve several useful functions, especially for the scientific personnel involved; but they do not give an integrated or coordinated account of the overall program and its importance to water pollution control in California. Such an account of the total program is the logical duty of the research consulting board, which has been following the various projects closely.

The purpose of this report, therefore, is to describe the origin, nature, scope, aims, progress, significant findings, and future plans of the entire marine waste disposal research program in California.

CHAPTER II

OBJECTIVES, SCOPE, AND FUNDING OF THE MARINE RESEARCH PROGRAM

OBJECTIVES

On 30 June 1957, shortly after its appointment, the research consulting board recommended that the following objectives be established for the submarine outfall research program:

1. The *overall objective* shall be to develop fundamental data and information relating to the effect of waste discharges on the marine environment so as to permit a more scientific evaluation of the many factors involved in the analysis, design, and operation of marine waste disposal facilities.

2. Among the many factors, which might be classified as *specific objectives,* primary importance shall be attached to:

a. resolution of water mass movement in near-shore waters.
b. fundamentals of mixing and dispersion of wastes in receiving waters.
c. qualitative description of movement of surface films and floatable material.
d. viability of organisms of enteric origin.
e. significance of coliforms, *E. coli,* enterocci or other organisms as indicators of pollution and contamination.
f. quantitative biological, chemical, and physical description of representative areas unaffected by waste discharges.
g. quantitative biological, chemical and physical effects of waste discharge on marine environment.
h. evaluation of indices and parameters for the chemical and biological assay of effects of waste discharge.
i. economic evaluation of marine resources of representative unit areas as related to water pollution control.

SCOPE AND LIMITATIONS

In preliminary considerations of the submarine outfall research program it had been envisioned by the former Executive Officer of the State WPC Board that a budget of $1,000,000 a year for four years would be required to execute all of the recommended projects. Unfortunately, however, funds of this magnitude could not be made available either from State or Federal sources, or from both. Consequently, it has been necessary to limit the scope of the research program to stay within the available budgets. This limitation has meant that some projects have had to proceed at a slower pace than originally anticipated while others have had to be deferred until initial projects were completed.

SOURCES AND DISTRIBUTION OF FUNDS

The programs of research described in this report have been financed through the State WPC Board with funds obtained from three sources:

1. Appropriations made by the California State Legislature to the State WPC Board.
2. Federal grants to the California State WPC Board under Public Law 660 of the 84th Congress.
3. A special grant from the Western Oil and Gas Association for the study of oil on beaches and near-shore waters (see Chapter VII).

The amount of these funds in each fiscal year and their distribution to specific research projects is shown in Table I.

Table I

Sources and Budgeted Distribution of Funds for Submarine Outfall Research Program. California State Water Pollution Control Board. 1956-1959.

Chapter Reference	*Project*	*1956-57*	*1957-58*	*1958-59*
III.	Oceanographic survey of continental shelf area of southern California	$100,000	$138,000	$125,000
IV.	The effects of waste discharges on kelp	----	20,000	20,000
V.	North coastal oceanographic investigations	----	11,000	20,000
VI.	Investigation of current measurement	----	7,000	----
VII.	Oily substances on the beaches	----	*(25,000)	----
VIII.	Tracer techniques in flushing and pollution studies of estuaries	----	----	11,050
IX.	Engineering evaluation and development of bioassay methods	----	----	4,500
--	International conference	----	----	1,000
--	Research consulting board	6,000	9,620	9,000
	Totals	$106,000	$185,620	$190,550
	State funds	50,000	75,000	79,000
	Federal funds	56,000	110,620	111,550

* Funds provided by the Western Oil and Gas Association.

COROLLARY RESEARCH PROJECTS

In addition to the projects listed in Table I, the State WPC Board, acting through its Executive Officer and with the assistance of the research consulting board, has been partly responsible for obtaining financial assistance from the National Institutes of Health and the Robert A. Taft Sanitary Engineering Center of the U.S. Public Health Service for additional marine research of a corollary nature. The projects supported by NIH or carried out by personnel of the USPHS are identified as follows:

1. "The Study of Benthonic Foraminifera and Their Relationship to Ocean Pollution" by Robert E. Stevenson, Johanna M. Resig, and John R. Grady of the Hancock Foundation, University of Southern California, supported by the National Institutes of Health at an annual budget of $19,967 for four years commencing 1 February 1959.

2. "Conference on Waste Disposal in the Marine Environment" by E. A. Pearson, Conference Chairman, University of California at Berkeley, supported in part by the National Institutes of Health at a budget of $5,317.

3. "The Development of Analytical Methods to Characterize Oily Substances as to Origin and Type", performed by A. A. Rosen and his associates at the Robert A. Taft Sanitary Engineering Center, Cincinnati, Ohio upon request of the California State WPC Board (see Chapter VII).

Several other research projects that are related to waste-disposal practices are currently being sponsored in California by the National Institutes of Health. These projects, however, are not being coordinated by the State Water Pollution Control Board.

CHAPTER III

OCEANOGRAPHIC SURVEY OF CONTINENTAL SHELF AREA OF SOUTHERN CALIFORNIA

Data that have been collected for many years on bacterial concentrations near ocean outfalls and on factors affecting these concentrations such as currents and die-off rates, provide at least a beginning for evaluating the effect of sewage discharges on the ocean in respect to pollution by enteric bacteria. In contrast, the effects of waste discharges on the normal fauna and flora of the sea are practically unknown, except for the more obvious effects in heavily contaminated estuaries and bays, or where there are substantial sludge deposits.

For discharge into the open sea or large estuaries, little basis exists for specifying effluent qualities in respect to protection of fish, the food chain of fish, and other natural resources of the ocean.

The lack of knowledge in this field is attributable in part to the difficulty of securing the necessary kinds of information, in quantity and of quality that will serve to correlate waste discharges with parameters of the marine ecology. It is necessary, among other things, to study extensively the plant and animal life of the sea, and to study the chemical and physical factors of the native ocean water and the ocean floor in respect to their effects on this marine life.

OBJECTIVES

1. To develop quantitative biological, chemical, and physical descriptions of representative marine areas unaffected by waste discharges.

2. To determine quantitative biological, chemical, and physical changes in marine ecology as a result of waste discharges.

3. To develop quantitative indices and parameters for the biological study of effects of waste discharges.

CONTRACTING, FUNDING, AND PERSONNEL

The extensive investigative program of the State WPC Board on waste disposal into marine waters was started in the last part of 1956. The phase of the research program defined by the foregoing objectives was undertaken at that time by the Allan Hancock Foundation of the University of Southern California.

The research vessel of the Foundation, Velero IV, is an important asset for this work. A highly competent staff had been assembled, and scientific studies of marine biology and geology had been carried on by the Foundation in earlier years. In 1955 and 1956 the Foundation conducted an intensive investigation of Santa Monica Bay for the City of Los Angeles, for the purpose of predicting the effects of the proposed effluent and sludge outfalls at Hyperion.

The first contract for the work financed by the State Water Pollution Control Board was for the period from 1 November 1956 to 30 June 1957 with payments of $99,200. With modifications to adjust for varying coverage of the different phases of the work as the project has progressed, renewals were made on 1 July 1957 and 1 July 1958 for one-year contracts in the amounts of $138,000 and $125,000 respectively. The work on foraminifera, described in Sec. 6 of the Significant Findings, is supported by a grant from the National Institutes of Health, USPHS. Director of the project during the period covered by this summary was Dr. Robert E. Stevenson. Those assisting were Mr. Elazar Uchupi, Mr. Donn S. Gorsline, Dr. Richard B. Tibby, Mr. R. D. Terry, Dr. E. Yale Dawson, Dr. J. Laurens Barnard, Dr. Olga Hartman, Mr. Gilbert F. Jones, and Miss Johanna M. Resig.

RESEARCH PLAN

The region studied in this project extends from the Mexican border to Point Arguello, a distance of about 270 miles. Along most of the coast there is a distinct shelf of gently sloping bottom out to a depth of about 300 feet, beyond which in many areas there is a rapid drop to much greater depths. This area is referred to as the mainland shelf. The study was mostly limited to this shelf, or to the area from near the shore to a depth of 300 feet. The width of the shelf varies from about 1 mile to 14 miles, averaging a little less than 5 miles. The study area totals about 1,300 sq. miles.

The research conducted under the terms of the 1 July 1958 agreement by and between the State WPC Board and the Hancock Foundation of the University of Southern California was intended to include but not necessarily be limited to the following specifications:

A. **Sampling**

1. *Area Types.* Sampling shall be conducted in the following types of areas:
   a. Representative areas unaffected by waste discharges at present and likely to remain so.
   b. Areas unaffected by waste discharges at present but likely to become affected in the future.
   c. Areas affected at present by waste discharges.
2. *Areas to be Examined*
   a. Four to six areas of each of the types (shown under item 1 above) shall be examined. The number of areas for each type and the boundaries of each such area shall be decided by the Contractor in conference with the State.
   b. In addition, two areas shall be examined where definitive benthic communities are known to the extent that statistical analyses can be made of seasonal variation, growth rates, settling, turnover, and other ecological factors.

3. *Sampling Locations*
   a. The total number of sampling locations under item A2a shall not be less than 100. The Contractor shall make a reasonable effort to exceed this number. The sampling locations shall be determined by the Contractor in conference with the State.
   b. The total number of sampling locations under item A2b shall not be less than 18.

4. *Frequency of Sampling*
   a. The 100 minimum sampling locations under item A3a shall be sampled once during the period of this agreement for biological constituents and twice for all other specified parameters.
   b. The 18 minimum sampling locations under item A3b shall be sampled four times during the period of this agreement for biological constituents only.

B. **Bacteriology.** Enteric bacteria shall be determined only when the concentration of such bacteria is presumed to be significant for the interpretation of other data.

C. **Biology**

1. *Pelagic*
   a. Plankton (phytoplankton and zooplankton) shall be sampled and analyzed at all sampling locations under item A3a at two depths at each location or at four depths at every other location. Quantitative analyses shall identify and enumerate principal species.
   b. Plankton representative of the pelagic community structure at approximately half of the locations under item A3b shall be sampled and analyzed for identification and enumeration of principal species.

2. *Benthic*
   a. Principal species shall be identified and enumerated, and biomass determined, at all sampling locations under item A3a.
   b. Organisms representative of the community structure at all locations under item A3b shall be identified, enumerated, classified as to size, and biomass determined, with such data being related to seasonal variations.

3. *Attached Plants.* Inter-tidal sampling and quantitative analysis of algal communities shall be made at selected and representative sampling locations to be determined by the Contractor in conference with the State.

D. **Physical and Chemical Characteristics of Water**

1. *Physical*
   a. *Temperature* (BT traverses) shall be determined at all sampling locations.
   b. *Transparency* shall be determined by Secchi disc observations at all sampling locations, supplemented by occasional hydrophotometer analyses.

2. *Chemical.* The following chemical characteristics of the ocean water shall be determined at the specified sampling locations:
   a. *pH.* At two or more depths at each sampling location.
   b. *Dissolved Oxygen.* At two or more depths at each sampling location.
   c. *Salinity.* At two or more depths at each sampling location.
   d. *Radioactivity* (gross counts or gamma). Surface samples at one or more selected locations in each sampling area.
   e. *Inorganic Nutrients.* The following inorganic nutrients shall be determined at two or more depths at one or more selected locations in each sampling area:
      (1) Silicate.
      (2) Phosphate.
      (3) Nitrate.
      (4) Ammonia.

E. Chemical Characteristics of Bottom Sediments

1. *Sampling Technique.* Core samples shall be taken at all sampling locations where bottom characteristics are such that this type of sampling is possible. Chemical characteristics shall be determined on core samples only.
2. *Lithology.* Lithological descriptions shall be obtained for all cores.
3. *Chemical Tests.* The following chemical tests shall be made on the upper part of all cores:
   a. Calcium carbonate ($CaCO_3$).
   b. Chemical oxygen demand.

SIGNIFICANT FINDINGS

The information obtained to date has been divided into the following classifications:

1. The Marine Climate of Southern California.
2. Characteristics of Sediments on the Mainland Shelf of Southern California.
3. Characteristics of the Waters Over the Southern California Shelf.
4. Attached Intertidal Algae.
5. Benthic Biology of the Mainland Shelf of Southern California.
6. Studies of Foraminifera.
7. Microbiology of the Coastal Waters.

The findings for the first two years of this project, up to about the end of 1958, are presented in Publication No. 20 of the California State Water Pollution Control Board. The summary here given is based essentially upon Publication 20, but, for the purpose of aiding the reader not familiar with the subject matter, supplementary information is sometimes used. Hence, statements given herein are not in all cases limited to those expressed in Publication 20.

The following sections described significant findings in the several phases of the project.

1. The Marine Climate of Southern California

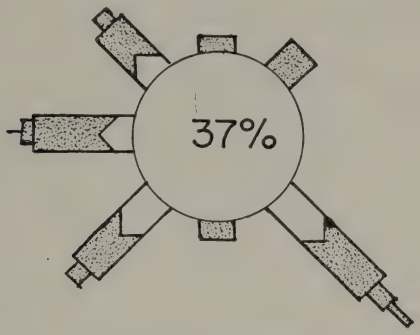
The climate of southern California is characterized by moderation resulting from the effect of cool adjacent ocean waters. During daylight, the land warms to a temperature higher than the air over the ocean and tends to create a breeze toward the land, preventing extreme temperatures in the coastal communities. Figure 2 shows two typical wind roses, compositing data for March 1956 and March 1957, but segregated as to morning and afternoon winds. In the morning, no wind is strongly dominant, and for 37% of the time it is essentially calm. The most prominent wind is from the southeast, since at that time of the day the land is mostly cooler than the ocean. In the afternoon the wind from the west is strongly dominant, and there is rarely any wind from land to sea during normal weather.

The pattern of morning winds shown for March is fairly typical of the whole year except for a greater component of northeasterly winds from November to February. In the afternoon, the northwest winds are somewhat stronger in later months, becoming dominant in September and October and frequently exceeding 15 knots. Winds of gale force are rare even during winter storms.

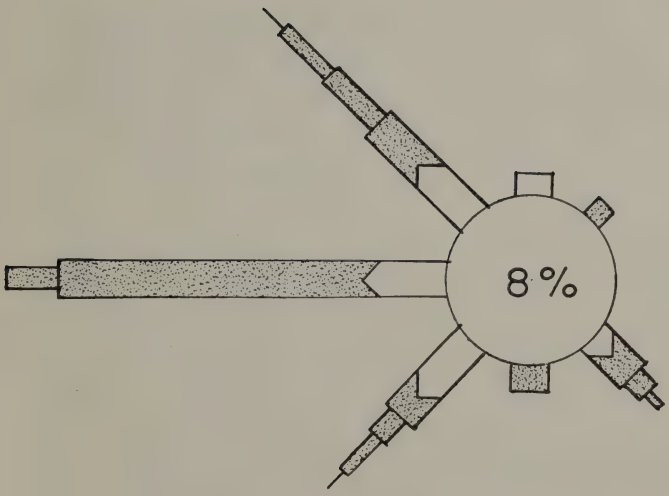
In view of the northwest-southeast trend of the coast, the force exerted by the temperature difference is toward the northeast in the day and southwest at night. The wind directions are somewhat to the right of these forces. A general eastern Pacific high-pressure area tends to increase the westerly winds, and contributes to a net landward movement of air. The mountain ranges generally paralleling the coast impede this air flow, and sometimes result in the same air mass being held along the coast, oscillating back and forth between night and day for several days at a time, with consequent accumulation of atmospheric pollutants over the metropolitan areas.

A general movement of water from the north, known as the California current, together with little-explored deep currents and upwelling, keep the ocean at a temperature lower than along the east coast at the same latitude. Although the ocean becomes progressively warmer going down the west side of the continent, land temperatures increase more, and rainfall declines from very heavy along the coast of British Columbia to moderate along central California, light along southern California and very slight several hundred miles farther south in Baja California. Cyclonic storms from the northwest reach southern California from time to time in the winter, but never in the summer. Rainfall is practically limited to the months from October to April. Storms of tropical origin water the southern tip of Baja California, and in rare cases reach as far north as Los Angeles.

Because of the low average annual rainfall of southern California, ranging from 10 to 20 inches on the coastal plains and valleys, large perennial rivers do not exist. A number of rivers of small size, i.e. the Ventura, Santa Clara, Los Angeles, San Gabriel, Santa Ana, Santa Margarita, San Dieguito, San Diego, and other smaller streams, formerly discharged continuously into the ocean. Diversion and pump-



MORNING WIND



AFTERNOON WIND

NUMBER IN CENTER OF WIND ROSE IS PERCENTAGE OF ZERO & VARIABLE WINDS

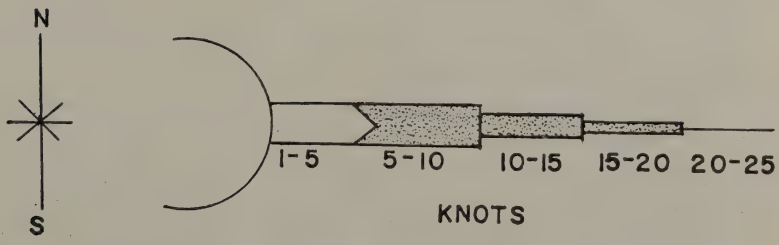


Figure 2

AVERAGE MORNING AND AFTERNOON WINDS, IN SANTA MONICA BAY, FOR MARCH

Combined data for 1957 and 1958

ing from the porous alluvium over which they flow have reduced the summer flow of most of them to zero.

After severe winter storms, the rivers in their natural state were raging torrents. In extreme cases, flows exceeded 100,000 cfs as on the Santa Ana River in 1938. With relatively steep gradients, they flushed huge amounts of sediment into the ocean. For purposes of flood control and water conservation, most of these flows have been controlled by dams, so that even in winter the runoff from the land is now much less than what it once was.

No careful study has been made of the total natural flow from the land into the sea before construction of dams, but it is roughly estimated that for all streams between Point Arguello and the Mexican border, the mean annual discharge was 1,000,000 acre feet. In many years the total was small, in others it was several times the average. Dams and diversions have probably cut in half the mean annual discharge to the ocean.

Off the southern California coast the ocean now receives about 700 mgd of sewage and industrial wastes, or about 800,000 acre feet per year. The principal change in the nature of the total land discharge to the ocean has been a decrease in the amount of sediment reaching the ocean, an increase in the dissolved nutrient elements, a leveling out of the rate of discharge, and a small increase in the total discharge.

2. *Some Characteristics of Sediments on the Mainland Shelf of Southern California*

Among the many factors that affect the kinds and quantities of living organisms on the bottom of the sea, there is probably none more determinative than the nature of the bottom. Under natural conditions a wide range of plant and animal communities is found on the bottom. The question of effects on bottom life of composition of the overlying water, or of substances added to the water by waste discharges, is of central interest in the research sponsored by the State Water Pollution Control Board. In the interpretation of any observations of plant and animal life on the bottom near a waste discharge, the nature of the bottom and its effect on natural biota must be taken into account.

The nature of the bottom on the continental shelf of southern California has been a subject of intensive study in the Hancock Foundation project. More than 700 bottom samples were collected and examined for the benthic data in Publication No. 20. To those may be added others taken by the Hancock Foundation during other projects, as well as notations by the U. S. Coast and Geodetic Survey. All such information has made it possible for the Hancock Foundation to draw a fairly detailed "soil" map of the shelf, and to develop descriptive correlation of bottom conditions with biota.

The position of the southern California shoreline in recent geologic times has been influenced predominantly by the ice ages, although variations have also occurred because of crustal movements. In parts of the Pleistocene era, the sea was about 100 feet higher than now, extending inland for many miles across what are now the coastal plains, and cutting terraces that can be seen along the hills from Palo Verdes to La Jolla. At lowest ebb, about 20,000 years ago, the level was about

300 feet lower than now, with the shoreline approximately at the edge of the mainland shelf.

At present, the shoreline consists of cliffs for 210 of the 270 miles from Point Conception to the Mexican border. These cliffs are slowly being eroded away. The detailed shape of the coast where cliffs prevail is determined in large part by variations in the hardness of the rock. The embayments have received detritus from the rivers, mostly at times of storm flow; sandy beaches have built up from this material. Detritus from erosion of the cliffs contributes in a minor way to the beach sands. The sands are not stable, but show a southeasterly drift that is caused by the predominance of waves striking the shore obliquely from the northwest. This drift exceeds 100,000 cubic yards per year along most of the southern California beaches, reaching 1,000,000 cubic yards per year on the shore of the Oxnard Plain.

The shelf is gashed by submarine canyons, extending quite close to shore, which act as traps for the sand. The sand that they accumulate will slide periodically, starting intense density currents that flush the sand out into deeper waters.

The material constituting the ocean bottom out to the edge of the shelf is composed predominantly of recent sediments from the land, generally ranging from sand at the shore to silt farther out. Quartz and feldspar are the principal minerals, but biotite (mica) is often prominent, becoming predominant in some of the deeper bottoms. Rock is not common except near the shore, but residual rock fragments are found in a few places. A coarse residual sand from an earlier cycle of deposition, particularly a distinctive red sand, is found in some areas on the Santa Monica, San Pedro, and San Diego shelves. Glauconite, which is a residue of alteration of iron-bearing silicates such as biotite, coats sand grains or forms nodules or granules of greenish "glauconite sand" on extensive areas of the deeper bottoms. Bottoms consisting predominantly of shells are scarce in the northern part of the area, but are found in some large areas on the San Diego shelf.

For the purpose of estimating relative amounts of organic matter in the bottom sediments, it was concluded that nitrogen determinations were most practical. As an approximation, the dry weight of organic matter can be considered to be about 18 times the weight of nitrogen. Nitrogen values tend to be low in the coarse sediments and higher in the fine sediments, presumably because the sedimentation characteristics of organic matter are similar to fine sediments. There is, in general, an increase of nitrogen with increase of distance from shore. At the 300-foot contour it averages 0.062%, corresponding to about 1% of organic matter, or 10 milligrams per gram of sediment.

Abnormally high nitrogen concentrations are found in the sediments in the vicinity of the outfalls of Los Angeles County Sanitation Districts and City of Los Angeles. There is an area of approximately a square mile around the diffusers of the Los Angeles County Sanitation Districts, and a smaller area around the Los Angeles outfall, wherein the organic content is such that the sediment is black and has an odor of hydrogen sulfide. Considering the broad grid used for this survey, the remaining outfalls are apparently contributing such small relative volumes of material that their influence is negligible.

Variation of nitrogen content with depth within the sediment was not explored. It must be assumed that there is a variation. Consequently the results must be considered as relative and as having quantitative significance only in relation to the sampling method employed.

Determinations were also made of calcium carbonate concentrations in the sediment. These concentrations are controlled by the relative rates of deposition of calcium carbonate and of other sediment. Both shellfish on the bottom and the minute foraminifera populating the water and the ocean floor lead to deposition of calcium carbonate. With increasing distance from shore the percentages of calcium carbonate have a tendency to increase, presumably because of slower rates of deposition of other sediment.

3. Characteristics of the Waters Over the Southern California Shelf

a. Nutritive Elements

Of the many chemical substances found in the sea, particular interest attaches to compounds of phosphorus, silicon, and nitrogen, because of their importance in the metabolism of plants and animals. It may be that lack of one or more of these nutrients is a limiting factor in marine growth. It can be argued that an increase in available nutrients, such as those contributed by sewage may be of actual benefit in the over-all food chain of the area. If the nutrients cause increased plankton concentrations, an increase of turbidity may be noticed, which may be esthetically objectionable.

With exceptions hereinafter noted, the data thus far secured do not show significant areal variations in the area studied. The results do conform to the well-known variation with depth. Surface waters are depleted of nitrate, phosphate, and silica by organisms which sink after death, and replenishment takes place principally from decomposing remains on the bottom. Phosphate was generally found to be from 0.01 to 0.05 mg/l (as PO_4)* at the surface, and from 0.05 to 0.20 mg/l at 200 feet depth. Silica ranged from a trace to 0.3 mg/l (as SiO_2) at the surface, and from 0.6 to 1.0 mg/l at 200 feet depth. Determination of nitrate presents analytical problems; hence only limited data were secured. The amounts more or less parallel phosphate, being roughly twice as great.

The condition near Point Arguello differs somewhat from the normal pattern, because deep water tends to upwell there, bringing up water carrying larger amounts of nutrients than generally found at corresponding depths elsewhere along the coast. For example, between Point Arguello and Santa Barbara, the phosphate content of the water at 150 to 200 feet averages 0.16 mg/l, while between Newport and Laguna the corresponding average is 0.07 mg/l. However, surface samples under normal conditions show low concentrations in all areas.

Near Port Hueneme, very high SiO_2 values, around 20 mg/l, were found on one occasion, a large outflow from the Santa Clara River being the evident cause. Near the outfall of the Los Angeles County Sanitation Districts, surface phosphates of 0.05 and 0.10 mg/l and silica of 0.20 and 0.30 mg/l were noted, these concentrations being

* Note that 1.0 mg/l of phosphate (PO_4) equals 10.52 microgram atoms per liter of phosphorus; 1.0 mg/l of nitrate (NO_3) equals 16.15 microgram atoms per liter of nitrogen; and 1.0 mg/l of silica (SiO_2) equals 16.67 microgram atoms of silicon.

greater than would be expected under natural conditions. The absence of demonstrable increases near Santa Barbara, Ventura, Orange County or elsewhere is not to be interpreted as meaning that waste discharges in those areas have no effect, but that the stations for which data are thus far available were not close enough to detect such changes.

b. Dissolved Oxygen

The solubility of oxygen in sea water at temperatures prevailing in the study area ranges from 9 mg/l at the lowest temperatures to 7 mg/l at the highest temperatures. Oxygen concentration at the surface generally does not differ greatly from saturation, but has some tendency to be on the high side, owing to photosynthesis. The most-noticeable high oxygen concentrations were found in the area from San Diego to the Mexican border, where 9 of 19 determinations in the upper 50 feet showed concentrations between 9 and 10 mg/l, one was between 10 and 11 and one was above 11 mg/l. More recent results, not included in Publication 20, indicate that such high oxygen values represented a temporary rather than a normally prevalent condition for this area. A few of the samples taken near Laguna Beach and near Port Hueneme showed concentrations above 9 mg/l. Between Santa Barbara and Point Conception a small amount of supersaturation was found, but no sample had more than 9 mg/l.

Dissolved-oxygen concentrations have a downward trend with depth below the upper mixed layer, which is generally 40 to 100 feet thick. Most of the concentrations around the 200 feet depth were found to be in the range of 5 to 7 mg/l. At times and places where upwelling of deep water occurs, low concentrations may be found near the surface. In some parts of the world, anaerobic sulfide-containing water comes to the surface, but such conditions are unknown off the California coast. The lowest oxygen concentration found on the shelf was 4.8 mg/l in a sample at 25 feet depth near Port Hueneme.

Since oxygen is produced by photosynthesis, one might expect to find some relationship between oxygen concentration and phytoplankton numbers. The data show that there is a slight tendency for high oxygen concentrations to accompany high phytoplankton counts, but the correlation is very poor, showing that other major factors are involved.

The foregoing generalizations about dissolved oxygen are to be considered somewhat tentative, as they are based upon data that may be greatly amplified in subsequent work.

c. Hydrogen Ion Concentrations (pH)

Determinations of pH give values ranging from 7.5 to 8.6. Photosynthesis uses up carbon dioxide and produces oxygen, while aerobic decay, which is an opposite reaction, produces carbon dioxide. The pH of the water is fixed by the ratio of bicarbonate ion to carbon dioxide. Thus photosynthesis tends to cause pH to rise, and decay tends to cause it to fall. It is for this reason that in sewage oxidation lagoons there is a strong tendency for pH and dissolved oxygen to rise and fall together. In the ocean samples there was only slight correlation in this direction. There are a number of reasons for this anomaly, a major one being that the actual amounts of photosynthetic oxygen in the samples were almost negligible in comparison with the buffer capacity of sea water.

d. Transparency

The transparency of near-shore waters has recently received considerable attention where the ocean is used for the disposal of sewage effluent. Transparency is important for esthetic reasons. Also, it controls the depth to which light will penetrate in sufficient intensity to support growth of marine plants. It is a factor in the rate of heating of the upper layers of the ocean by the sun, and it may be useful in identifying water masses.

Transparency is determined by the absorption of light by water, by dissolved substances in the water, and by suspended matter. In this project, two kinds of tests have been used in exploring transparency. One measures light absorption, using photoelectric cells. The other is the Secchi disc test, in which a white metal disc 30 cm in diameter is lowered into the water, and the depth is read at which it is no longer visible. A rough sort of inverse correlation exists between Secchi disc readings and light absorption. However, they do not measure the same thing, so close correlation should not be expected. The depth to which one can see is determined mostly by the particulate matter, which scatters the light and produces a diffused or foggy appearance, until the image is no longer seen. Considerable absorption of light by molecular substances could occur without loss of clarity. The photometer readings, on the other hand, provide a measure of the depletion of the light in passing thru a column of water, including the depletion due to scattering by particulate matter as well as that which is absorbed by substances that do not reduce the clarity of the water. Each test has its appropriate usefulness. The photometric method will serve to show how much light is available for photosynthesis at different depths, and can be arranged to determine light at different wave lengths. It will also serve to determine the light absorbency of water at different depths. The Secchi disc, on the other hand, shows how far one can see into the water, giving results of greatest significance for rating the appearance of the water.

The data obtained in this project where the two methods were used simultaneously show a rough correlation which may be represented by the equation

$$L/L_0 = 0.175 - 0.0015D$$

where L/L_0 is the fraction of incident light remaining at the depth D in feet where the Secchi disc is no longer visible. The correlation is poor, even within the experimental limits. In some cases D might be twice as great or half as great as would be indicated from the equation.

Secchi disc readings are usually low in waters close to the shore. Beyond this proximity, there is a zone within which the readings are generally between 20 and 40 feet. A zone beyond this, with Secchi disc readings up to 60 feet, is considered very clear water. Readings exceeding 60 feet in waters over the mainland shelf have been found in an area between Point Conception and Santa Barbara, and in an area near Oceanside. The clearest mid-ocean waters show Secchi disc readings as great as 120 feet.

Future investigations will provide more complete information, so that more detailed deductions will be possible. For the present, it may be said that the zones of more turbid water tend to be narrow along

rocky shorelines and wider along beaches. There are wide areas of water with Secchi disc readings less than 40 feet between Santa Barbara and Port Hueneme, in Santa Monica Bay, off Long Beach, and south of La Jolla. It is difficult at the present time to discern the difference between natural causes and human activities in these turbidity patterns. The picture may become clearer as more data are secured.

e. Temperature, Salinity, and Density

The temperature structure of the water in Santa Monica Bay was the subject of intensive study by the Bureau of Sanitation of the City of Los Angeles and by Hancock Foundation in connection with design of the new outfall of the City. Los Angeles County Sanitation Districts have made studies off the San Pedro Hills, and much work has been done in different projects by the City of San Diego. The studies by Hancock Foundation in the present project have added information from a broad area.

Briefly, it may be said that surface temperature readings have ranged between about 15° and 25° C at the southern end of the study area, and between about 14° and 19° C near Santa Barbara. The maxima are usually in August, the minima in February. At a depth of 200 feet, the range is 11° to 20° C in the southern area, and from 11° to 14° C in the northern area. The temperature at the surface is always greater than at 200 feet, although the difference may be only 1° to 2° C in the winter. It is generally 5° to 10° C in the summer.

A surface layer mixed by waves and currents tends to keep the temperature rather uniform down to depths of 20 to 60 feet in the summer, and sometimes down to 150 feet in the winter. The mixed layer, of course, does not have a sharp boundary, so there is a transition zone between this and the relatively unmixed deeper water. There is a relatively steep temperature gradient in this transition zone, often called the "thermocline." It is most pronounced in the summer when there is the greatest temperature difference between surface and depth.

Surface temperatures lower than would otherwise be expected are sometimes found where there is upwelling.

The regular annual temperature cycle does not cause the same temperatures to be repeated in successive years. There was a general rise in temperatures over the entire eastern Pacific in 1957, with temperatures at the end of the year and the first part of 1958 being several degrees higher than at corresponding times in some other years.

Temperature is of interest because it is one of the major factors affecting organic growth. It is also of great importance in the design of ocean outfalls because of its effect on the density structure of the ocean. When sewage or other waste water having a density similar to that of fresh water is discharged into the ocean, it rises because of the difference in density. As it rises it is greatly diluted with the surrounding water. When it reaches the surface, the mixture is in proportions that depend principally upon depth, the diameter of the discharge port, and the quantity of flow. Even the largest sewage flows, if discharged at a depth of 200 feet seldom reach the surface with more than 1% sewage in the mixture. When there is a large density difference between top and bottom water, the mixture at the surface may be heavier than

the surrounding sea, and may tend to sink again, or may stop before reaching the surface, as is evident in some deep outfalls now in use.

Salinity also affects the density of the sea water. Extensive information has been collected during this survey on salinities, and from salinities and temperatures the density may be calculated. The effect of salinity off the southern California coast is minor. The maximum difference at any station amounts to about 0.6 parts per thousand (ppt) of NaCl, but the variations are mostly in a smaller range. A difference of 0.10 ppt has the same effect on density as a temperature difference of 0.8° C.

Salinity usually shows little variation down to a 200-foot depth in the summer. In the cooler months, salinities increase with depth, thus tending to reinforce the weak temperature gradient that prevails in those months.

4. Attached Intertidal Algae

Along the coast between Point Conception and Point Loma, 42 shore stations were selected for sampling of attached vegetation. Representative communities of such vegetation cannot exist where there is only a sandy bottom. About half of the coastline affords good anchorage for vegetation; hence, the stations were selected to be representative of these rocky shores. Locations were carefully fixed and strips were laid out perpendicular to the shore, which were searched to collect all species of attached plants that constitute significant elements of the flora. Voucher specimens of the plants have been collected, prepared, identified, and filed in the herbarium of the Hancock Foundation. Individual stations have been visited from one to four times. In the course of time, the data will serve to discern trends or seasonal effects. The careful annotation, identification, photographing, and preserving of specimens will provide an excellent base for comparing present conditions with conditions at any future time. By contrast, there are only meager reports to serve for estimating the variety of species at a few coastal points in earlier years.

Figure 3 shows the numbers of species at 38 of the 42 stations as a bar graph. It was reported that the other four were found to have substrata too limited for comparison with the other stations. Results of more than one visit to a station were averaged. The graph relates only to diversity of species, and does not indicate total amount of growth. The average number of species found at the various stations was 27.

Dr. Dawson mentions the following factors as ways in which human activities may alter the littoral flora:

Sewage and industrial waste discharges.
Sports fishing.
Kelp harvesting.
Animal and plant collecting.
Bathing beach cleaning.
The scattering of "soluble chemical refuse" over the watershed.
Damage of exposed plants by atmospheric contamination.

The above listing does not imply any order of importance.

Among the 38 stations shown in Figure 3, one is very close to the Port Hueneme outfall, with specimens collected 25 to 50 feet from the discharge. The number of species is 15, and there is a great predominance of articulated coralline algae of the genera *Boisiella* and *Corallina*. An abnormal flora is clearly related to the sewage discharge.

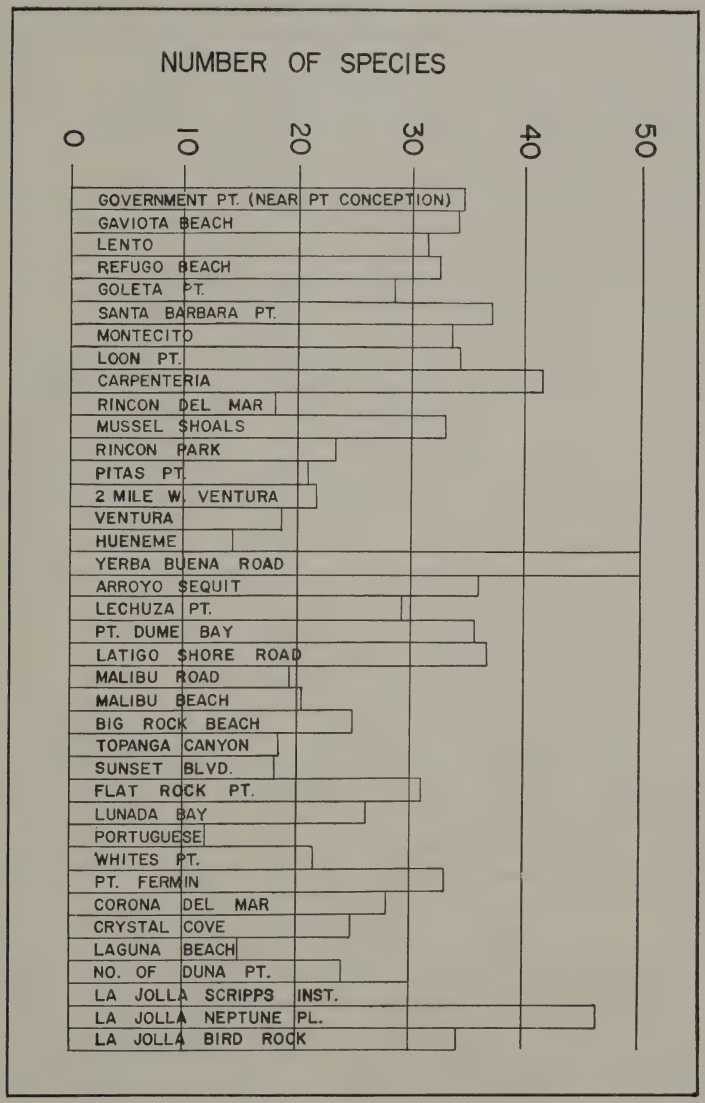


Figure 3

NUMBER OF CONSPICUOUS SPECIES AT 38 ALGAL STATIONS BETWEEN POINT CONCEPTION AND POINT LOMA

At Whites Point the number of species is 22. Historical data indicate that there may have been 50 or 60 species of plants in the general area in the first part of this century, although presumably a somewhat smaller number would have been found along a narrow transect as used in the sampling for this investigation. Construction of a tunnel under the San Pedro Hills with dumping of muck in the ocean, just prior to the survey, as well as the proximity of the large outfalls discharging 5,000 to 8,500 feet off shore, are considered responsible for a reduction in number of species and for the predominance of Corallines. Portuguese Point, located four miles west of the discharges, shows only 12 species. Bacterial tests have shown that this area is well within the reach of effects of the outfalls, and it is presumed that a lack of diversity in that location is also the result of the outfalls.

At Laguna Beach, near the former outfall of the city, and at Ventura, 3,400 feet from the end of the outfall of that city, reductions of numbers of species are also attributed to the outfalls.

On the north side of Santa Monica Bay, from Santa Monica to Malibu, there appears to be a reduced diversity of algae and loss of the more delicate forms, especially by comparison with data obtained in 1912 and 1913. Local sewage disposal cannot be a factor at the Sunset Blvd. station, since sewage from that area is pumped to the Los Angeles system. From Topanga Canyon to Malibu Road there is mostly private sewage disposal with no outfalls. Presumably there is some seepage of septic tank effluent from the seaside residences through the ground into the ocean. Such seepage would contain the same components as natural seepage, but probably with considerable increment of nitrogen. However, the effect on the natural nitrate content of the littoral water would be insignificant. It has been suggested that these seepages may be having an effect on the algae. It is also possible that the Hyperion outfall of the City of Los Angeles, discharging 270 mgd, may be a factor. Tests have disclosed surface waters two miles north of the Los Angeles outfall having nitrogen concentrations more then 100 times as great as are normal for the upper 50 feet of the coastal water. The beaches under consideration are 9 to 13 miles north or northwest of the outfall. It may be that water from this discharge may reach the shores on the north side of the bay in sufficient amount to change in a substantial way the nutrient content of the water, and hence have an effect upon the biological balance.

The presence of normal vegetation in some situations is as important as its absence in other places, in attempting to determine the range of effect of outfalls. The outfall of the City of Santa Barbara, discharging 4.5 mgd at a distance 3,200 feet off shore, is between sampling stations at Santa Barbara Point and Montecito, which are, respectively, $1\frac{1}{2}$ miles west and $2\frac{1}{2}$ miles east of the discharge. No adverse effects on the intertidal algae at these stations were noted. The sewage treatment plant at Carpinteria discharges about $\frac{1}{2}$ mgd into the surf zone not more than a few hundred feet from the Carpinteria sampling station. The number of species here is 42, ranking third among the 38 stations.

Point Fermin is 2.0 miles east of the discharge of the Whites Point outfalls, discharging 260 mgd. The predominant movement of water from the outfall is toward the west, but many years of testing by Los

Angeles County Sanitation Districts have shown coliform bacteria at Point Fermin for more than half of the time in concentrations higher than prevailed in the early 1930's. Spread of the sewage field to Point Fermin has been observed many times. Thus, the water in this location for part of the time is virtually of pristine purity, and for part of the time has some sewage contamination. No adverse effect on vegetation was noted. Lunada Bay, located near the most westerly projection of the Palos Verdes Peninsula, is 11 miles south of the Los Angeles City discharge at Hyperion, and seven miles northwest of the Los Angeles County discharge at Whites Point. Flat Rock Point, on the north side of the peninsula, or south side of Santa Monica Bay, is nine miles south of Hyperion, and 10 miles from Whites Point, but around the western projection of the peninsula from it. Lunada Bay and Flat Rock Point are not reported as showing subnormal vegetation.

The manner in which sewage discharges may affect the attached marine plants has not been discussed by Dr. Dawson. Comments are here offered which may help to clarify seemingly irreconciliable facts.

One way in which sewage may affect the flora is by a toxic action. But information about known toxic substances which may be in sewage, and about apparent toxicity of sewage itself, indicates that the concentrations which could be reached in some of the places where vegetation appears to be affected are orders of magnitude lower than the lowest amounts known to have any discernible effect. This does not preclude an oligodynamic effect of unknown substances on species having unique susceptibilities, but the hypothesis that this is a factor would have to be treated as highly tentative until the obtaining of some evidence to support it.

Another way in which vegetation could be affected would be by a change of salinity, but the changes of salinity that could result from sewage discharges near any of the sampling stations, with the probable exceptions of Port Hueneme and Carpinteria, are less than the natural range of variation of the coastal waters.

Turbidity caused by the sewage discharge might be a factor. It is being seriously studied in the case of the giant kelp (see Chapter IV) where the amount of light reaching depths of 30 to 60 feet is important. Sewage-caused turbidity in the surf zone, however, is insignificant in comparison with natural turbidity at any of the sampling stations except probably at Hueneme. Muddiness of the water from the tunnel construction at Whites Point may have been a factor.

The most conspicuous way in which sewage may change the environment is by the addition of nutrients. As noted hereinbefore, nitrogen concentrations two miles from the Hyperion outfall have at times been found to be more than 100 times as great as normal for the general area. Part for part, the scarce nutritive elements have more conspicuous effects on aquatic growths than do most toxic substances, yet are present in sewage in far higher concentrations than any toxic substances known to be in sewage.

Certain species of plants have adapted themselves to growing on extremely low concentrations of nutrients. These species may not be very hardy otherwise, and under conditions more favorable for other species they may be crowded out. In this way, and in others, it is

evident that an increase of nutrients may ultimately profoundly change the whole flora and fauna. While it is difficult to see how toxic substances present in sewage could affect the flora except very close to the outfalls, it seems possible that the nutrients might have effects wherever the concentration is materially increased above naturally occurring levels. However, natural levels of the common nutrients along the coast seem to be adequate to support very large phytoplankton populations, and there is merit in the view that attached algal growths are not limited by a scarcity of these elements.

Changes in the intertidal flora may occur from natural causes or from causes unrelated to waste discharges. Dr. Dawson makes a comparison, from his own observations, of the La Jolla Neptune station in 1943-44 and now. There has been an extensive change in the type of plants, but waste discharges are so remote that they are not considered to be a factor.

5. Benthic Biology of the Mainland Shelf of Southern California

A study which promises to be a monument in the development of marine biology, as well as in the evaluation of effects of waste discharges into the ocean, is the sampling and biological analysis by the Hancock Foundation of the ocean bottom on the southern California mainland shelf. Thus far, the investigation has been mostly between depths of 30 and 300 feet.

Samples are taken by means of a Hayward orange-peel grab. Depending upon the softness of the bottom, this procedure will generally secure from 5 to 80 liters of sediment, intercepting from $\frac{1}{8}$ to $\frac{1}{4}$ of a square meter of the surface. A general basic spacing plan was adopted on a grid of about 2 minutes of latitude and longitude, but closer spacings were often used for special purposes and repeat samplings have been made in some areas. Biological observations on about 400 samples are reported in Publication No. 20. In addition similar data have been secured by Hancock Foundation in corollary projects, all of which serve in the construction of a comprehensive picture of the benthic biology in this area, and in studying the effects of the outfalls.

In the 400 samples reported in Publication No. 20, about 1500 principal species have been identified and enumerated, with a typical sample containing about 100 species. In 119 of the samples, there has been a complete analysis of all specimens larger than 1.5 mm in length. The attempt to identify all species has been a heroic undertaking, for more than a third of all species and many whole genera, have not heretofore been described or named.

The richness of the benthic fauna is astonishing to those not acquainted with the coastal ocean floor. Even those who are familiar with the ocean floor by sight may be unaware of the profuse life that is buried in sandy or muddy bottoms. The samples that have been completely counted down to animals of 1.5 mm size have an average of about 4,700 individuals per square meter, with an average total weight (drained of water but not desiccated) of 260 grams per square meter. Even these numbers may fall short of the total, for some animals may be buried beyond the reach of the orange-peel grab.

The most abundant single species is *Amphiodia urtica,* a small red "brittle star" of the ophiuroid class of echinoderms, having long flexible arms which break easily. They are found in about three-quarters of all samples. They are most abundant in depths of 150 to 300 feet and average 91 per sample for all stations, or about 600 per square meter. The number of individuals of this species in the study area is more than a trillion. (See Figure 4) Other ophiuroid species are found in smaller numbers.

The most abundant order are the polychaete annelid worms, most of which are buried in tubes or burrows in the bottom. Species of one family or another are found at nearly all stations, averaging about 300 per sample. (See Figure 5)

A remarkable concentration of the echiuroid annelid worm, *Listriolobus pelodes* is found between Santa Barbara and Ventura at depths of 50 to 150 feet. It is a short fat worm which lies buried in the mud, characteristically in a soft sticky mud, feeding by its long tongue

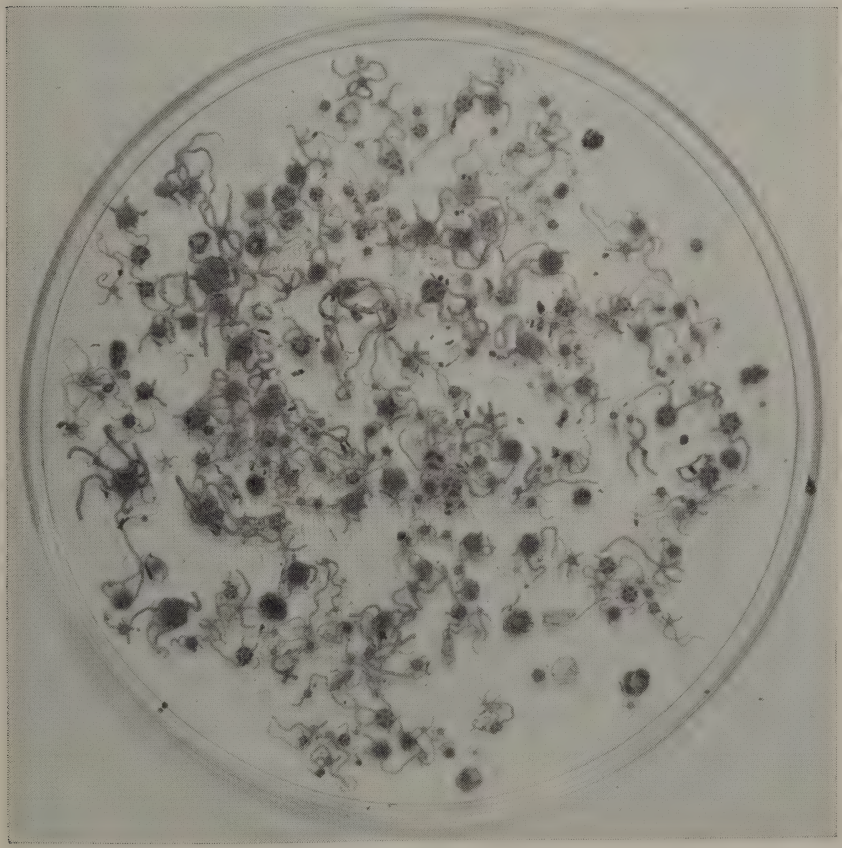


Figure 4

***AMPHIODA URTICA*, THE SMALL RED BRITTLE-STAR**
Part of aggregate

Figure 5

TUBES OF THREE CLOSELY RELATED POLYCHAETES, CONSTRUCTING TUBES OF CONTRASTING DESIGN: *DIOPATRA OBLIQUA; D. ORNATA* SHOWING PARTS OF THREE TUBES, ONE WITH SPECIMEN PARTLY EVERTED; AND *D. TRIDENTATA*, PARTS OF ONE TUBE WITH SPECIMEN

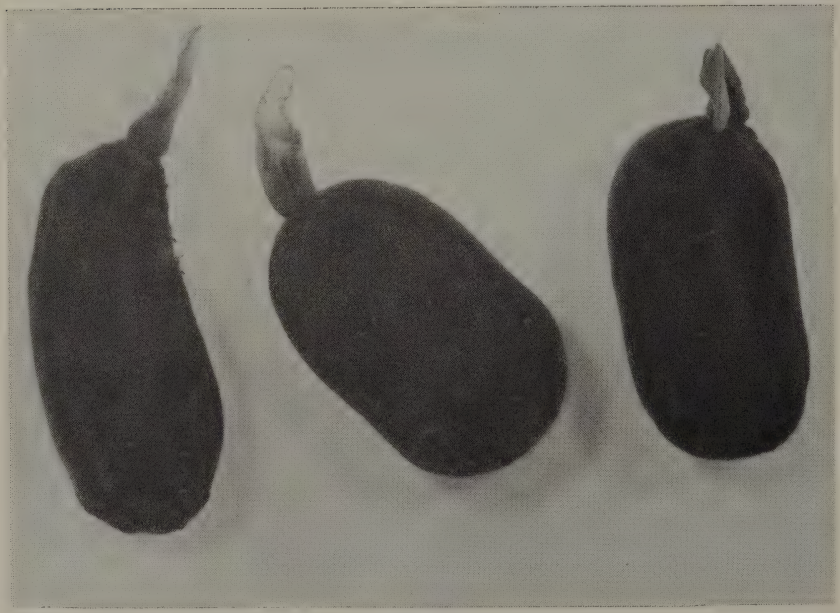


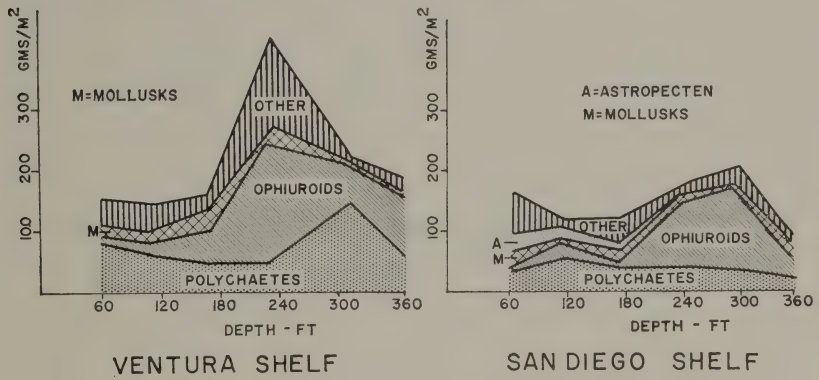
Figure 6

***LISTRIOLOBUS PELODES*, A TONGUE-WORM, SHOWING THREE INDIVIDUALS**

(Figure 6). It is found in numbers as high as 75 in a sample, which, because of the size (about 8 grams) represents considerable biomass. From the standpoint of mass, it is highly dominant in Santa Barbara area. The total weight of this species in the area is several hundred thousand tons.

The holothurians or "sea cucumbers," a class of echinoderms, are represented principally by two rather large species. They form a considerable part of the biomass in depths a little beyond the principal range of *Listriolobus* on the Santa Barbara shelf.

Figure 7 shows distribution of various divisions of animals in three areas, from the standpoint of mass.



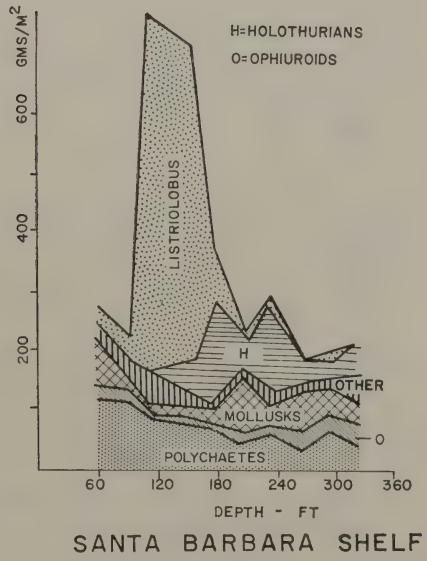


Figure 7

BENTHAL BIOMASS DISTRIBUTION ON SECTIONS OF THE MAINLAND SHELF OF SOUTHERN CALIFORNIA

Figure 8 shows distribution by numbers. Here the crustaceans represent about 25% of the total. The species found were mostly very small, hence they do not appear as a major component of the biomass in Figure 7. The principal changes with depth as shown in Figure 8 are a decrease in the polychaetes and an increase in the echinoderm as depth increase. However, there is stratification by species within these classes.

Mollusks are generally less numerous than the worms, crustacea, and echinoderms. They consist mostly of clams, with snails secondary.

From north to south there is a logical increase in the numbers of warm-water species and a decrease in the numbers of cold-water species.

Depth tends to affect biomass, or the total weight of the biota, because of the varying rate of deposition of food. On the other hand, the nature of the bottom is often an important factor, especially in determining which species will thrive. Many other factors lead to such complex patterns of distribution that generalizations are cautiously restricted.

Of major interest is the effect that ocean outfalls have on this benthic life. One of the effects which may be expected from a marked

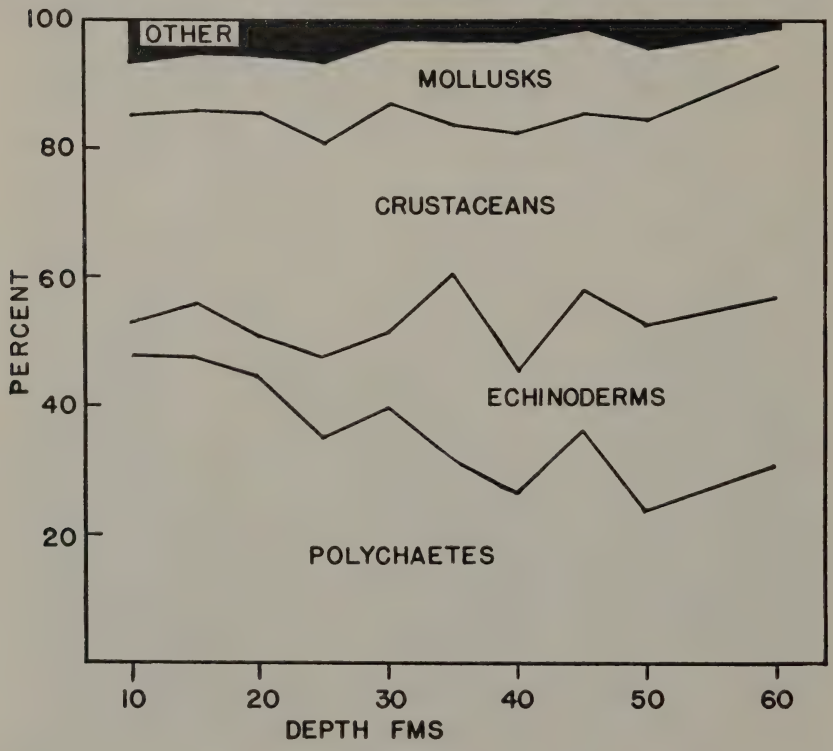


Figure 8

DEPTH DISTRIBUTION OF SPECIMENS BY PHYLOGENETIC GROUP

The preponderance of a few groups (polychaetes, crustaceans, echinoderms, and mollusks) is illustrated.

change in the environment is a change in the diversity of the biota. A toxic environment generally results in a reduction of the number of species down to a few which can resist the toxic effect. An enrichment of the environment also generally results in a reduction of the diversity, because a few species outgrow all of the others.

One way to indicate diversity is by use of a bioindex which represents the ratio of number of individuals to number of species, or, in other words, the average number of individuals of each species. A high bioindex means less diversity. Obviously this index is dependent upon the size of sample and other elements of the technique. Bioindices have been reported for the 119 stations completely analyzed. These values cannot be compared with bioindices obtained by any technique other than one identical in all respects with the technique used in this research, but they are comparable among themselves.

It is clear from the data that there are no effects discernible for any great distance from the outfalls. This is not to say that there may not be some effects, but such effects appear to be so slight compared to the effects of even very minor natural factors that it is impossible to distinguish them.

It is reported that there were 10 samples near enough to ocean outfalls, and otherwise normal, to study possible effects. Three of these had higher than average biomasses and appeared to be abnormal in a degree that suggests a possible effect of the outfalls; one near the Whites Point outfalls of Los Angeles County Sanitation Districts, one near Marineland, about 4½ miles north of Whites Point, and one 5800 feet west of the Hyperion outfall of the City of Los Angeles. In all three cases, the reduction of diversity is attributable to a larger number of individuals of less than the normal number of species, and not to a lack of total crop. For all three, the number of individuals per square meter was well above the average of all stations, and the biomass was high. The other 7 of the 10 stations that might be within the range of influence of outfalls showed normal bioindices. A more conclusive evaluation of relationship of waste discharges to the findings at these stations and at other stations in the vicinity of ocean outfalls awaits completion of certain phases of the study.

6. Studies of Foraminifera

Foraminifera are minute single-celled animals possessing shells called tests. They achieve locomotion by means of protoplasmic pseudopodia and may be biologically classed under Phylum Protozoa, Class Rhizopoda, Order Foraminifera. Forms living off the southern California coast average less than 1 mm in size and encompass a great variety of shapes, as more than 45 genera are represented.

Members of the Order Foraminifera, known commonly as "forams" live both on the sea floor as benthos and in the overlying water as plankton. Tests of both types occurs in the bottom sediments, planktonic tests being contributed when the animals die. Attention in this investigation was directed to the bottom-dwelling types, since they can be expected to show a closer correlation with environmental conditions than can the tests that are dropped from the variant ocean currents.

More than 100 species of benthonic foraminifera were counted. The total number of individuals identified and counted in samples from 236 stations was in excess of 50,000. Per gram of sediment, the numbers of tests were usually below 40, but sometimes reached 1,000.

By staining techniques, live and dead forams were distinguished, and live/dead ratios were calculated for all samples. These ratios are dependent essentially upon rates of deposition of sediment. Live forams stay on the surface, but dead tests are buried. Thus, a high live/dead ratio means a high rate of sediment deposition and a low ratio means a low rate of deposition. Sometimes the numbers living were more than half of the total number of tests, but usually they were a small fraction of the total. There were no significant differences in the species distribution of the living and dead tests.

The benthonic forms are divided into three groups: (a) hyaline, with tests constructed of calcium carbonate with many perforations and generally a glassy appearance; (b) porcellaneous, with calcium carbonate tests lacking the numerous perforations, and (c) arenaceous, with tests consisting of sand grains cemented with calcium carbonate. Hyaline forms are in general strongly dominant on the southern California shelf. Arenaceous forms are generally minor, but are dominant in some samples. Porcellaneous forms rarely exceed 10% of the total.

Interest centers in the effect of waste discharges on the forams, particularly in respect to the possible use of these organisms as indicators of the condition of the water.

The data indicate that arenaceous forms, and particularly *Eggerella advena* and *Trochammina pacifica,* may become dominant in the vicinity of outfalls. That is the case, at least, in the vicinity of the Whites Point and Hyperion outfalls. Close to the Whites Point outfall, where there is a large accumulation of organic matter, the bottom is anaerobic. In these areas there is a depression of all bottom life, and in some samples there were no living forams.

There is no evident effect of the Orange County outfall (third largest in southern California), and the possible effects of the other smaller ones are as yet uncertain.

7. Microbiology of the Coastal Waters

Plankton are defined as the floating or weakly swimming organisms of a body of water. They may be large floating organisms such as jellyfish, medium-sized organisms such as small crustacea, or plants and animals consisting of a single cell or a few cells. Plankton of the small category, or microplankton, are the particular subject of the biological studies of the coastal waters by Hancock Foundation.

The most conspicuous characteristic of the occurrence of these plankton is the great range of variability. A normal range of numbers might be considered to be from 100 to 10,000 per liter, but sometimes the numbers reach many millions. Occurrences of numbers of large magnitude are called blooms. Blooms may appear and spread rapidly until they extend, in exceptional cases, for several hundred miles along the coast, but usually as a narrow band.

When numbers are in the normal range, the plankton are not detrimental and are commonly considered to be contributors to the food

chain which ultimately supports fish growth. In high numbers they sometimes produce a beautiful luminescence of the waves at night, since some species are photogenic. In other respects they may be very troublesome. They increase turbidity, causing the water to appear brownish-red when the numbers are high. These extreme blooms are called "red tide." When a bloom starts to die out, it may result in depletion of oxygen, with possible suffocation of fish, and it may produce an offensive odor. Some species produce toxins, which may kill fish or may be absorbed by mussels, leading to fatal poisoning of people eating the mussels. At concentrations up to 1,000,000 cells per liter, the greatest objection to high plankton concentrations is the esthetic one of reducing the pleasing blue color of clear ocean water.

The plankton that cause the conspicuous red tides are of the Order Dinoflagellita or dinoflagellates. These are motile, one-celled photosynthetic organisms.

The causes of plankton blooms are mysterious, with little other than hypotheses as attempted explanations at the present time. The explanation that first comes to mind is a variation of the concentration of nutrients in the water. There is reason to believe that the low concentrations of nitrate and phosphate commonly found would not support the very high blooms. In fact, in the heavy red tides the dry weight of cells sometimes exceeds 50 mg/l. It would not be possible to produce this weight of cells with a few hundredths of a milligram of nitrogen per liter as found in many of the coastal seawater samples, unless there is significant tropistic concentrating of the organisms. On the other hand, there does not appear to be any correlation between nutrients and plankton numbers up to many thousands per liter, and ample nutrient concentrations do not necessarily result in plankton blooms.

In respect to ocean outfalls, there is an opinion among oceanographers in southern California that when a plankton bloom does start along the coast, it is likely to be intensified where the water carries nutrients from an ocean outfall. One bit of evidence for this is that high plankton counts are characteristic of San Diego Bay, and heavy blooms occasionally appear there. This bay receives much sewage effluent and is only slowly flushed by the tides. Elsewhere along the coast, there is as yet too little quantitative information to establish the extent and amount of effect of outfalls on these blooms. It is noteworthy that the heaviest bloom observed in this general area in recent years was a red tide in 1958 starting along 300 miles of the coast of Lower California which for most of the distance is practically unpopulated. The water near Ensenada was described as looking, when viewed in the mass, like tomato soup. A concentration of 15,000,000 cells per liter was found in a sample from Ensenada Bay. The bloom was a nearly pure culture of *Gonyaulax polyedra.* It spread along the coast of California and near La Jolla a count of 20,000,000 per liter was found. The bloom continued as far north as Santa Monica Bay, where counts of a few million were found. The bloom generally did not extend very far from shore—usually less than a mile. Observations on this bloom, including effects on fish and kelp, and observations on conditions in San Diego Bay, are presented in reports of the Institute of Marine Resources at La Jolla. The foregoing discussion draws on information from those reports.

Observations by personnel of Hancock Foundation on microplankton have not been directed toward specific studies of algal blooms, but rather to the determinations of general conditions, and, if possible, the regional and seasonal variations, and the effects of other characteristics of the water on the plankton numbers.

Water samples were collected at the sea surface and with Nansen bottles at about 25, 50 and 150 feet. They were preserved with formalin. A 100-ml portion was centrifuged for 15 minutes at up to 2,500 rpm, and the plankton concentrate reduced to six drops. A microscopic examination was made of an amount corresponding to 8 ml of the original sample. The numbers were expressed as organisms per liter.

The samples that had been examined up to the closing date for inclusion of data in Publication 20 totaled 800. In view of the many factors which influence the numbers of microplankton and the great variability of the numbers, few generalizations can be made. For example, it is of interest to know to what extent ocean outfalls may affect the numbers. Plankton samples were collected in the vicinity of the Orange County outfall on five days. Low counts were found two times, medium counts one time, and high counts two times. The vicinity of the Los Angeles County Sanitation Districts' outfalls was visited three times, with low counts on all three occasions. It is evident that it would not be valid, on statistical grounds, to conclude that the Orange County outfall causes high plankton counts and that the outfalls at Whites Point do not. The counts obtained thus far in vicinities of the three largest outfalls of southern California average 2,000 per liter, which is just the same as the average for all of the other samples along the coast. This comparison might seem to prove that the outfalls are without effect on the plankton counts, but it would be a premature and oversimplified conclusion.

Down to the depths of 50 feet there does not seem to be much difference in the numbers, but at 150 feet they average about a quarter as great as at the surface.

The plankton are made up predominantly of phytoplankton (including dinoflagellates under this heading). Diatoms are the most important class, but dinoflagellates are sometimes a substantial part of the total, particularly in red tides. Other classes of phytoplankton sometimes amount to 40% of the total count.

Protozoa usually constitute less than 10% of the count, but reach 40% as an extreme.

FUTURE PLANS

Sampling and analyses are expected to continue through the Spring of 1960, after which the field work of the project will be terminated. The great accumulation of data, however, warrants a thorough collation and evaluation, which will probably be undertaken during the 1960-61 fiscal year. Shortly after July 1961, a comprehensive final summary of the entire project should be available for reproduction and distribution.

COROLLARY PROJECT

It is significant to note that a project was initiated by an investigator of the Hancock Foundation to study the effects of waste discharges on

animals in marine and estuarine waters, independently of the work described in this chapter. This project is sponsored by the National Institutes of Health, USPHS, with title, designation, and investigator as shown below:

"Investigation of Pollution on Marine Invertebrates," Project RG-4911, by N. T. Mattox

REPORTS AND PUBLICATIONS

1. "A Preliminary Report on the Biology of the Continenal Shelf of Southern California," date 30 June 1957, reproduced and distributed by the Allan Hancock Foundation, University of Southern California. (Mimeographed)

2. "Oceanography and Marine Geology of the Southern California Shelf," interim report dated 7 August 1957, reproduced and distributed by the Allan Hancock Foundation, University of Southern California. (Mimeographed)

3. Annual Reports, 1957-58 and 1958-59, reproduced and distributed by the State Water Pollution Control Board. (Multilithed)

4. "A New Genus of Phoxocephalid Amphipoda (Crustacea) from Africa, India, and California," by J. Laurens Barnard, *Annals and Magazine of Natural History*, Ser. 12, vol. x, p. 432, June, 1957.

5. "A New Genus of Haustoriid Amphipod from the Northeastern Pacific Ocean and the Southern Distribution of *Urothoe Varvarini* Gurjanova," by J. Laurens Barnard, *Bulletin*, Southern California Academy of Sciences, vol. 56, part 2, p. 81, 1957.

6. "A Remarkable New Genus of Corophiid Amphipod from Coastal Marine Bottoms of Southern California," by J. Laurens Barnard, *Bulletin*, Southern California Academy of Sciences, vol. 57, part 2, p. 85, 1958.

7. "Generic Partition in the Amphipod Family Cheluridae, Marine Borers," by J. Laurens Barnard, *Pacific Naturalist*, vol. I, No. 3-4, p. 3, March 16, 1959.

8. "Liljeborgiid Amphipods of Southern Coastal Bottoms with a Revision of the Family," by J. Laurens Barnard, *Pacific Naturalist*, vol. I, No. 3-4, p. 12, March 16, 1959.

9. "The Sea Bottom Off Santa Barbara, California: Biomass and Community Structure," by J. Laurens Barnard and Olga Hartman, *Pacific Naturalist*, vol. 1, No. 6, June 1, 1959.

10. "Isopods of Coastal Bottoms," by Menzies and J. Laurens Barnard. (In press)

11. "Common Pardaliscid Amphipods of California Coastal Shelf," by J. Laurens Barnard. (In press)

12. "Studies on Eddy Diffusion in Santa Monica Bay, California," by Richard B. Tibby. (In press)

13. "The Circulation of Santa Monica Bay, California," by Richard B. Tibby. (In press)

14. "The Distribution of Woody Debris in the Sediments of the Ventura Portion of the Southern California Coastal Shelf," by Gilbert F. Jones and Richard D. Terry. (In press)

CHAPTER IV

THE EFFECTS OF WASTE DISCHARGES ON KELP

The giant kelp, *Macrocystis pyrifera,* is a prominent feature of the nearshore marine environment of southern California and Baja California. It occurs normally in water 10 to 80 feet deep and it is usually associated with rocky bottoms, boulders, or large gravel. To these solid substrates the plant becomes attached by means of a tangle of root-like structures known as a "holdfast". In a few locations, however, giant kelp has been observed where the ocean bottoms consist of fine silt and sand. A diagrammatic representation of the major features of a young kelp plant is shown by Figure 9.

Large beds of giant kelp may be envisioned as marine forests. With plants towering to 100 ft., they provide shelter for smaller fish and

Figure 9

DIAGRAMMATIC REPRESENTATION OF A YOUNG KELP PLANT SUCH AS MIGHT BE FOUND AT POINT LOMA AT A DEPTH OF ABOUT 6 M.

The plant is depicted bent at an angle by a moderate current. Considerable detail is omitted for the sake of clarity. A. Holdfast. B. Primary stipe. C. Stubs remaining from original fronds. D. Sporophyll (reproductive blade) clusters. E. Developing young frond. F. Deteriorating senile frond. G. Bundle of stipes. H. Growing point of a mature frond in the canopy at the surface.

other marine fauna; they serve as a source of food for herbivorous fish and predators such as marine invertebrates; they can be harvested to yield products useful to man; and when uprooted by forces of nature they can be a nuisance and economic burden. About 100,000 tons of kelp are harvested annually in California and its value is estimated by the California Department of Fish and Game at about $20 per wet ton. Indeed kelp probably constitutes the greatest bulk of living material in the nearshore waters of southern California. The economic worth of standing beds of kelp to skindivers and fishermen (sport and commercial) is difficult to estimate, but it is certainly significant. On the debit side of the ledger, kelp dislodged by storms frequently washes ashore onto bathing beaches, from which it must be removed at considerable cost to municipalities and individuals.

During the past two decades, kelp beds have been observed to disappear or to recede near the outfall sewers of the Los Angeles County Sanitation Districts on the Palos Verdes peninsula and also near the mouth of San Diego Bay. Domestic and industrial wastes from these metropolitan areas have been implicated as causes of the kelp retrogradation.

Along with these observations, cognizance must be taken of the fact that large kelp beds have also disappeared in recent years along a 50-mile stretch of coastline south of Turtle Bay, far from any apparent source of man-made pollution. To becloud the circumstantial evidence still further, the outfall sewer from the City of Santa Barbara terminates about 300 feet seaward from a rather thick kelp bed that is apparently not being harmed by such proximity. Indeed, there is a possibility that surface growth might be stimulated by nutrients in the municipal wastes.

It is essential in the design and location of treatment plants and outfall sewers to understand and predict the effects of waste discharges on the ecology of receiving waters. For this reason, and in view of the anomalies concerning the disappearance and survival of *Macrocystis pyrifera*, the State Water Pollution Control Board authorized a research project to accomplish the objectives outlined below.

OBJECTIVES

1. To determine the effects of wastes discharged through ocean outfalls upon the survival, growth, and general condition of kelp.
2. To investigate the separate effects on kelp of such factors as:
   a. Turbidity
   b. Siltation
   c. Diseases, parasites, and grazers
   d. Nutrients
   e. Toxicity
3. To ascertain the concentrations of domestic sewage, industrial wastes, and components thereof in the sea water in kelp beds which are the maximum that the kelp can tolerate without being damaged.

CONTRACTING, FUNDING, AND PERSONNEL

Investigations relative to the ecology, physiology, and biochemistry of *Macrocystis pyrifera* have been underway for over a decade at the Scripps Institution of Oceanography and the Institute of Marine Resources (IMR) of the University of California, at La Jolla in San Diego. Initial phases of this research were sponsored by the Kelco Company from 1948 until 1957, largely to assess the effects of kelp harvesting on fish life and also on survival and growth of the beds. More recently, the general Kelp Investigation Program at IMR has been sponsored by the California Department of Fish and Game at an annual budget of $50,000. This research encompasses experimental ecology, physiology and biochemistry, growth and reproduction, effects of harvesting on kelp and on fish, culture and transplantation of kelp, changes in the extent of kelp beds, and natural causes of kelp bed deterioration.

In view of this background of fundamental and corollary information, and in light of the experience and training of its staff, the Institute of Marine Resources was the logical agency to investigate the effects of waste discharges upon kelp. Accordingly, an agreement was executed commencing 1 November 1957 between the State Water Pollution Control Board and the Regents of the University of California in the amount of $20,000 to accomplish the objectives outlined above. This agreement was extended for a second year commencing 1 July 1958 at an annual rate of $20,000. It was recognized by both parties to the agreement that the investigation will require a sustained effort of possibly four years' duration if significant results are to be obtained.

In general charge of the investigation is Charles D. Wheelock, Director of the Institute of Marine Resources. Personnel assigned to this project include Dr. Wheeler J. North, Acting Project Officer, in charge of the field investigations, and Dr. Kenneth A. Clendenning, in charge of laboratory research. Dr. North is being assisted by Earl G. Cunnison, James R. Stewart, Richard Cherry, and Charles T. Mitchell. Dr. Clendenning has the assistance of Mrs. Lois I. Rushing.

RESEARCH PLAN

It is the intent of the agreement that this research shall include, but not necessarily be limited to, the following program:

1. Compilation of historical accounts of the extent of the several kelp beds, particularly those near outfalls, a parallel compilation of such records as may exist of the nature and quantity of waste discharged from principal outfalls, and a compilation of pertinent oceanographic data.

2. Periodic ecological surveys of selected outfall areas, designed to observe and report the density, kind, and morphological appearance of the principal organisms (flora, fauna, and micro-organisms), as well as the influences of these organisms on the kelp environment.

3. A study of the effects of wastes on young and adult plants by experimentally introducing them into the areas adjacent to outfalls, and by laboratory experiments.

CONDUCT OF RESEARCH AND METHODOLOGY

This project has been integrated and co-ordinated with the overall Kelp Investigation Program of IMR, of which Dr. Wheeler J. North is also Project Officer. Both programs are under the general guidance of the Kelp Advisory Panel of IMR.

Field investigations to date have comprised (a) compilation of historical records of the extent of kelp beds at many locations, including studies of aerial photographs, (b) diving to observe the condition of kelp in many localities and to assess the effects of siltation, parasites, and grazers, (c) transplanting of kelp in specific areas to determine survival or degradation in relation to several ecological factors, (d) measurement of the light penetration of water under various conditions of turbidity and solar radiation, (e) the relation of harvesting to turbidity insofar as the condition of kelp is involved and (f) the effects of "red tide" and abnormally high temperatures during the summer of 1958 on existing kelp beds.

Laboratory investigations during the first year of the project have consisted largely of tests to determine the toxicity to young kelp plants of specific substances that might occur in sewage or industrial wastes. Conditions that are harmful to algae soon impair their photosynthetic mechanism and consequently this characteristic has been used as a basis for measuring toxic and other damaging effects. Young kelp fronds of about one meter length were collected by divers at a depth of 60 to 90 feet, brought to the laboratory in buckets of sea water, and held in flowing refrigerated sea water (14-15°C). Individual blades were removed with their bulbs and separated into two size groups, one from each group being exposed to the various test media. Under these conditions, the photosynthetic capacity of the blades in the sea-water control subsequently rises with time. If young bottom kelp blades in refrigerated sea water show equivalent gains in photosynthetic capacity when exposed to suspected toxic agents, the substance in this concentration is deemed harmless.

During the first year of the project, toxicity tests were conducted with San Diego Bay water, distilled water (to assess the effect of salinity), chlorinated and unchlorinated sewage, free chlorine, various metallic ions, synthetic detergents, chlorinated hydrocarbons, phenol, chlorinated phenols, diesel oil, and boiler fuel oil. Experiments were also conducted with the predominant "red tide" organism *(Gonyaulax polyedra)* and with marine leptotel, the suspended and colloidally dispersed non-living organic matter that accounts for most of the light absorption in coastal waters when the standing crop of phytoplankton is low.

SIGNIFICANT FINDINGS

1. Field investigations

a. A great many organisms have been observed grazing on *Macrocystis pyrifera* and fragments of this plant have been found in the stomachs of fish. Presumably, therefore, a part of the organic matters synthesized by kelp finds its way directly into the animal food chain.

b. The kelp beds at the southern tip of Point Loma, which suffered serious degradation the past decade, have exhibited a renewed growth of young kelp plants.

c. The disappearance of giant kelp in the Palos Verdes region is difficult to evaluate, but on the basis of present conditions the major adverse effects appear to be predation and turbidity, which diminishes subsurface photosynthesis.

d. It is conceivable that reduced photosynthesis may work concurrently with grazing to deplete kelp beds. If increased turbidity produces greater light attenuation, it is possible that grazing may occur faster than replacement by photosynthesis.

e. The dominant effect on kelp in southern California waters in 1958 was the influx and continued presence of warm coastal waters. Temperatures as high or higher than 20°C persisted well into November 1958. Most of the canopies of the beds had deteriorated, as is common, during warm summer temperatures. Regeneration of this important portion of the plants was delayed by persistent warm water. It has been reported by kelp harvesters that there is less *Macrocystis pyrifera* on the surface throughout all kelp beds in southern California at present than ever before in their experience (dating back to 1929). The extent of the beds has receded both in areas near ocean outfalls and in regions remote from such structures. Because of the widespread nature of the regression it is difficult to determine to what extent the recent (1958) losses at Palos Verdes or at Point Loma were attributable to effects of diluted waste waters. (While man-made influences may have some effects upon the growth, survival, and/or disappearance of giant kelp, it appears that natural phenomena such as increased temperatures of coastal waters may be far more widespread in their effects and for restricted periods may completely mask any local effects.)

2. *Laboratory investigations*

a. San Diego Bay water, sampled one mile north of the municipal outfall, was not detrimental to young kelp plants; but water collected directly over the outfall (with very little saltwater dilution) caused a rapid loss of photosynthetic activity. This effect may have been due in part to low salinity and high biochemical oxygen demand.

b. Reductions of 10 to 25 percent in salinity (by the addition of distilled water) cause a significant reduction in photosynthesis within 5 days, for bottom kelp fronds. Blades from the surface canopy were much less sensitive to salinity.

c. Chlorinated or unchlorinated municipal sewage at concentrations of 1 percent by volume were not harmful, but 10 percent caused serious disintegration in 5 days.

d. Chlorine in sea water, up to 1.0 mg./liter was not deleterious but 5 to 10 mg./liter caused marked damage in 5 days.

e. The toxic effects of heavy-metal ions range from mercury as the most severe through copper, zinc, lead, and nickel as the least toxic. Copper at 0.01 mg./liter was not deleterious but at 0.10 mg./liter toxicity was evident. Hexavalent chromium at 0.1 mg./liter showed no damage but at 1.0 mg./liter reduction of photosynthesis was evident, all within 5 days at 17°C.

f. There was no significant response in 5 days to 1.0 mg./liter of an anionic detergent (sodium dodecyl sulfate) but a dosage of 10 mg./liter was quite inhibitory. A cationic detergent (zephiran chloride) showed marked effects in 5 days at 1.0 mg./liter.

g. Phenol has a low toxicity level, with no significant effect at 9.4 mg./liter (10^{-4} molar concentration) and only a 30 percent reduction in photosynthetic activity after three days at 94 mg./liter.

h. Chlorinated phenols such as pentachlorophenol are extremely toxic, with concentrations of 2.66 mg./liter (10^{-5} molar pentachlorophenol) producing a complete loss of photosynthetic activity in four days.

i. Diesel fuel oil and boiler fuel in concentrations of 1 percent by volume produced almost complete cessation of photosynthetic activity in two days, with boiler fuel being more severe than diesel. Even a temporary three-hour exposure to 0.1 percent by volume of boiler fuel, followed by normal conditions, was detrimental.

FUTURE PLANS

During its first year of operation, this project has produced a great deal of new and useful information relative to the effects of waste discharges upon giant kelp. In the next year or two, it is anticipated that field investigations will throw more light on the relative effects of natural and man-made influences upon kelp. Moreover, it is hoped that specific threshold toxicity levels for many constituents of municipal and industrial wastes will be established.

REPORTS AND PUBLICATIONS

1. Annual Reports, 1957-58 and 1958-59, reproduced and distributed by the Institute of Marine Resources, University of California.

2. Quarterly Progress Reports, commencing 31 December 1957, reproduced and distributed by I.M.R.

CHAPTER V

NORTH COASTAL INVESTIGATIONS—AN OCEANOGRAPHIC STUDY BETWEEN THE POINTS OF TRINIDAD HEAD AND THE EEL RIVER

One of the specific objectives of the submarine outfall research program is the quantitative biological, chemical, and physical description of representative areas unaffected by waste discharges. Several representative areas on the continental shelf of southern California are being investigated by the Hancock Foundation, as described in Chapter III. All of them, however, involve warm semitropical waters with very little fresh-water discharge from the adjacent land mass. As such, they are not representative of the coastline north of Point Arguello and certainly not typical of the cold nearshore waters of northern California which receive tremendous flows from inland surface runoff.

The possibility of a marked increase in waste discharge in the Humboldt Bay area stimulated local interest in the present condition of the bay and nearshore waters. Attempts at State funding of a general investigation to be conducted by the staff of Humboldt State College were being made by local interests early in 1957. At this time the Research Consulting Board was brought in to consider the problem. The RCB recognized the desirability of obtaining quantitative data relative to the biological, chemical and physical characteristics of a marine area in northern California concurrently with the oceanographic survey along the southern coastline. With two such widely separated areas, differing in temperature, topography, geology, hydrology, and other controlling factors, a comparison of many background characteristics would be possible.

Upon recommendation of the research consulting board and with the strong support of the North Coastal Regional WPC Board, the State Board in 1957 authorized the investigation described below.

OBJECTIVES

To develop quantitative biological, chemical, and physical descriptions of two types of marine coastal areas in northern California:

1. Those unaffected by waste discharges and likely to remain so.

2. Those unaffected by waste discharges at present but subject to possible future modification.

CONTRACTING, FUNDING, AND PERSONNEL

By virtue of its location on the northern California coastline and its strong Division of Natural Resources embracing a fisheries staff and the elements of oceanographic research, Humboldt State College was the contractor for this phase of the submarine outfall research program. An agreement was prepared by 1 December 1957, but owing to administrative delays, final ratification did not occur until 7 March 1958.

The initial budget was $11,000 but the project was renewed during fiscal years 1958-59 and 1959-60 in the amount of $20,000 per year.

The project is being administered through the Division of Natural Resources, Dr. Charles F. Yocom, chairman, with Dr. George H. Allen, Assistant Professor of Fisheries, the project leader. Much of the field collection of data and samples, as well as the chemical, physical, and biological analyses, have been the responsibility of two graduate students, Jerry D. Larrance and Carl W. Sims. Several undergraduate students have assisted with field and laboratory investigations. Serving in an advisory capacity have been Dr. Ernest O. Salo and Mr. John W. DeWitt, Associate Professors of Fisheries.

RESEARCH PLAN

The marine research conducted under the terms of the agreements of 1 December 1957 and 1 July 1958 by and between the State WPC Board and Humboldt State College was intended to include but not necessarily be limited to the following specifications:

A. **Study Areas.** The specific study areas are to be determined in conference with the State and to lie between Trinidad Head and the Eel River. (See Figure 10.)

B. **Scope of Investigation.** The scope of the investigation shall be directed toward the development of physical, chemical, and biological descriptions of the overlying waters and benthic region.

1. *Overlying water.* The physical description of overlying waters will include:
   a. Temperature.
   b. Transparency.

   The chemical description of the overlying waters will include:
   a. pH.
   b. DO.
   c. Salinity.
   d. Phosphate (PO_4).
   e. Nitrate (NO_3).
   f. Silica.
   g. BOD.
2. *Benthos.*
   a. The physical descriptions of bottom samples will include general lithological descriptions.
   b. The chemical descriptions will include COD or organic carbon.
   c. The biological descriptions will include evaluation of biomass and identification and enumeration of principal species.
3. *Specialized Studies.* Consideration will be given to collection of information on:
   a. Phytoplankton—Enumeration of total organisms and identification and enumeration of principal species.
   b. Zooplankton—Enumeration of total organisms and identification and enumeration of principal species.

c. Ocean currents.
d. Fish and shellfish productivity.

C. **Sampling Frequency.** Frequency of sampling and analysis to be determined in conference with the State.

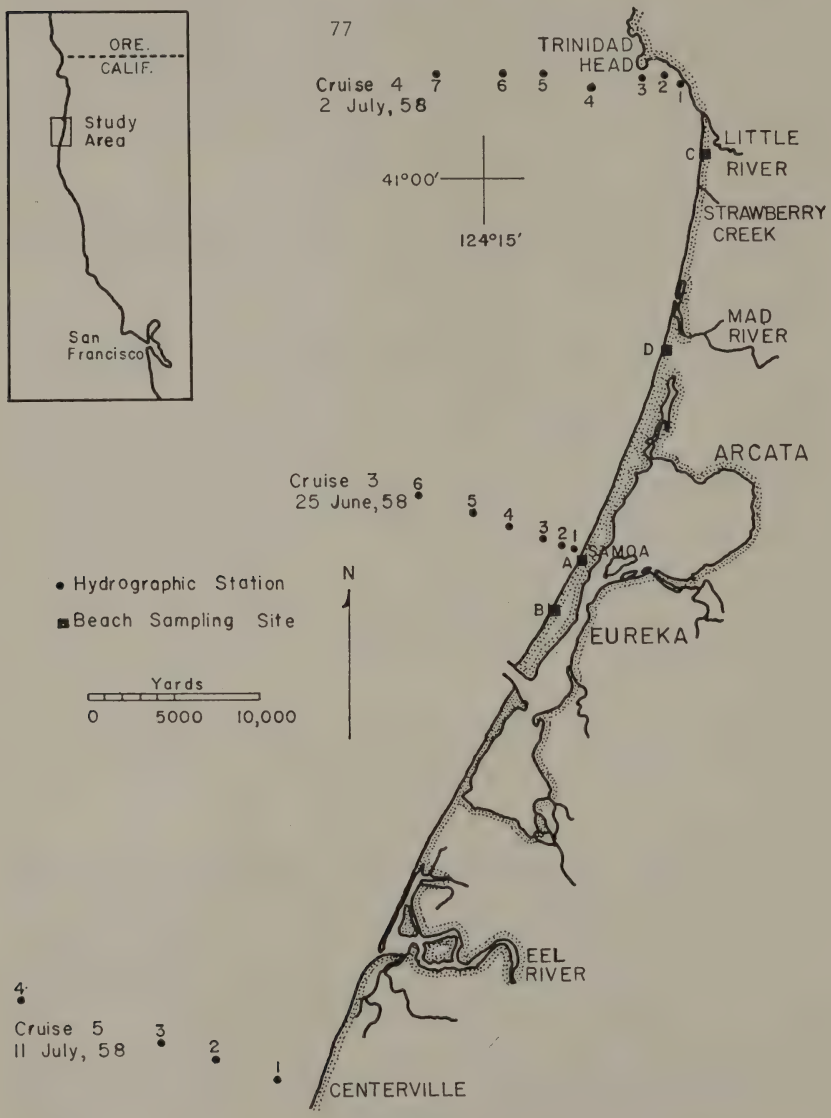


Figure 10

LOCATION OF NORTH COASTAL STUDY AREA, AND LOCATIONS OF OFF-SHORE AND ON-SHORE SAMPLING STATIONS

CONDUCT OF RESEARCH AND METHODOLOGY

The first eighteen months of this project have been devoted largely to collection of the oceanographic data specified in the research plan above. Inasmuch as the field procedures, sampling gear, and analytical techniques for such work were relatively new to the staff at Humboldt State College, there have been understandable delays in certain phases of the work. In general, the accumulation and analysis of chemical and physical parameters of the overlying water has proceeded according to the planned schedule. In addition, the examination of animals along the shoreline and intertidal area has been productive. Sampling and analysis of the benthic region awaited the procurement and testing of an "orange-peel" grab, but by June 1959 a grid of samples had been taken off Samoa. The "specialized studies" in the research plan have been undertaken with varying degrees of achievement as described below.

Hydrographic stations were established along the three lines indicated in Figure 10. These transects were selected for the following reasons: off Trinidad Head, the northern boundary of the study area, because the projecting topography here may strongly influence the nature of the nearshore currents; off Samoa Spit, because it lies approximately in the middle of the study area and appears to be a likely future site for marine outfalls; and off Centerville at the southern boundary of the study area, where topography of the Eel River Canyon may profoundly influence the oceanographic picture along the entire study area.

The four intertidal sampling areas are also shown in Figure 10. Stations A and B were located for coordination with the middle transect of oceanographic surveys; Station C, near the northern transect, as the center of an area supporting a sizable razor-clam population; and Station D for its potential influence from Mad River discharges. Shoreline sampling sites in the southern half of the study area were not established initially for reasons of economy of time and manpower; but an additional station has now been established at Table Bluff, located directly opposite the south end of Humboldt Bay.

Through June 1959, a total of 29 oceanographic cruises were undertaken, each with a limited objective of location, duration, or type of sampling. On most of these cruises, chemical and physical data relative to the overlying water were acquired. The more-recent cruises include studies of the benthos and macroplankton.

SIGNIFICANT FINDINGS

It is too early in the progress of this project to draw any firm and definite conclusions relative to the natural background of the study area as it may be related to the future submarine discharge of waste waters. There are, however, some general observations that may be made relative to the approximate magnitude of certain parameters.

1. Salinity, calculated from chlorinities determined by silver-nitrate titration, is reported as grams per kilogram, or parts per thousand. At most stations during the summer of 1958, salinities increased with depth, to a value of about 33.60 ppt at about 100 ft. The lower salinities at the surface may represent the effects of fresh-water discharges,

especially from the Mad River. The least saline water, 33.17 ppt, was found at Samoa, which is subject to the southward drift. The highest salinities were found at the deep stations taken off the Eel River. Extensive salinity data for the winter and spring of 1958-1959 have been collected and reported but not yet analyzed or summarized, by the contractor.

2. During the summer of 1958, ocean water temperatures varied from about 15°C on the surface near Samoa to about 7.5°C at about 500 ft. depth off the Eel River. No pronounced thermocline was observed. From October 1958 through April 1959 temperatures and salinities were more homogeneous in their vertical distribution.

3. Dissolved oxygen values present an interesting but somewhat confusing picture. During the summer months, there is an extreme stratification from high values at the surface to low ones at the deepest sampling spots. The highest value reported was 21.80 mg/l at the surface near the shore at Samoa on 5 September 1958, and the lowest was 2.34 mg/l at about 100 ft. depth in the Eel River marine canyon on 10 September 1958. Most surface values range from 8 to 9 mg/l except during July and August when they climb to the 10 to 11 mg/l range, owing to intensive photosynthetic action. The content of dissolved oxygen at depth is a function of the density structure resulting from temperature and salinity, and also the degree and extent of upwelling.

4. Phosphates, expressed as mg/l of PO_4,* are also intensively stratified during the summer and more mixed during the winter. At the surface, during the summer, phosphates were usually less than 0.05 mg/l, whereas every sample taken at 200 feet depth yielded a phosphate value of 0.25 mg/l or greater. During January and February, 1959, phosphates varied from 0.07 mg/l at the surface near shore to 0.19 mg/l at distant deep stations.

5. Transparencies, as measured by the Secchi disc, have been quite low in comparison with the clearer waters of southern California. Values range from a low of 4.5 feet close to shore at Samoa (21 April 1959) to 35-40 ft. at five miles. Most readings within two miles of shore are less than 20 ft.

6. The amount pH data is too sparse to permit evaluation of distribution in space or time, and analyses of nitrates and silicates were not accomplished prior to July 1959.

7. Biochemical oxygen demands of overlying water range from about 13 mg/l at inshore surface stations during summer months to almost zero at deep locations. High surface values may be attributed to plankton.

8. Intertidal sampling of animal populations during the summer of 1958 showed that, in general and as expected, species appeared to be distributed in horizontal bands. High upon the beach, the dry sand supports sand hoppers *(Orchestoidea)*. The pill bug, an isopod *(Exciralina)* was found in the region just above the low high-tide zone, while this zone proper contains beds of *Emerita* (sand crab) with accompanying populations of *Pontharpinia* (an amphipod). In addition,

* Note that 1.0 mg/l of PO_4 equals 10.52 microgram atoms of phosphorus per liter.

many polychaete worms are found in this zone. The sand bars farther out, awash at high tide, are characterized by large numbers of the mysid *Archaeomysis*.

FUTURE PLANS

It is expected that the program of sampling and analysis will continue for a total period of three to five years so that adequate chemical, physical, and biological data will be obtained to permit statistical evaluation of this representative north-coastal area.

PUBLICATIONS

1. Annual Report to California State WPC Board, submitted in September 1958. (Mimeographed)
2. Quarterly Progress Reports, to CSWPCB (Mimeographed).

CHAPTER VI

INVESTIGATION OF CURRENT MEASUREMENT

One of the most significant recommendations in SWPCB Publication No. 14, "An Investigation of the Efficacy of Submarine Outfall Disposal of Sewage and Sludge", dealt with the general problem of current measurement and resolution of nearshore circulation systems. Item 1 of the conclusions and recommendations presented in the aforementioned report is as follows:

"1. The problem of greatest practical importance in the rational design of a submarine outfall installation is one of adequate monitoring and resolution of the circulation system in the nearshore area in proximity to an outfall site. More precise information is needed than is currently available regarding the horizontal and vertical velocity characteristics of the nearshore system, not only at a single point but preferably at several points in the area. Current measurements are needed not only at or near the surface, but also simultaneously at several depths. Data of this type if taken during sufficient intervals of time will permit resolution of the circulation system as well as a partial separation of tidal and non-tidal currents.

"The Roberts Continuous Recording Current Meter appears to be ideally suited for the type of current observations required. The reported sensitivity of the meter of 0.1 knot and the facility of continuous recording of both velocity and direction with depth at several depths for periods up to 10 days without attention appears to be ideal for application to this problem. Concern regarding the lower limit of sensitivity of the instrument need not be great because the currents of greatest import in submarine outfall design are those of considerably higher magnitude. Also, of great concern is their frequency of occurrence.

"Because the latest Roberts Current Meter (Model III) is currently in the developmental stage, research in this area might be considered in two phases.

a. Testing and development of the meter to check and/or improve its suitability for measurement and recording of current circulation systems at outfall sites.

b. Development of cooperative current monitoring programs with existing municipalities and agencies engaged in the submarine disposal of sewage and/or sludge. The objective of such studies would be twofold. First, to provide information on current systems existing at the site of the cooperating agency, and second to permit resolution of tidal and non-tidal currents—the method of analysis, their magnitude, and application in rational design for critical or limiting oceanographic conditions".

OBJECTIVES

Owing to the apparent need for work in this area, the Research Consulting Board recommended that a preliminary exploratory project be supported to evaluate thoroughly the existing information relative to measurements of currents. The general objective of this investigation is to conduct an analysis and evaluation of existing and potential systems for measuring currents in both coastal and estuarine waters insofar as such currents relate to the movement, transport, and dispersion of discharged waste waters. This objective is intended to lead to recommendations for application or development of continuous or semi-continuous recording equipment for current strength and direction measurement at multiple depths.

CONTRACTING AGENCY, FUNDING, AND PERSONNEL

The contractor for this investigation was J. W. Johnson, Consulting Engineer and Professor of Hydraulic Engineering at University of California, Berkeley. Mr. Johnson was assisted by R. L. Wiegel in the evaluation of data and preparation of the report. The contract with Mr. Johnson dated 15 January 1958 was in the amount of $6,000.00. The report was submitted to the State Water Pollution Control Board on 1 September 1958.

RESEARCH PLAN

The investigative program included the following general and specific subject areas:

A. Review of pertinent literature.
   (a) Meters
   (b) Recording and/or transmitting systems
   (c) Data resolution systems

B. Consideration of problems related to current resolution in wind wave, swell, and tidal systems.
   (a) Effect of wind wave
   (b) Effect of swell
   (c) Effect of tidal changes
   (d) Effect of other factors such as
      (1) Size of current sensing element
      (2) Type of mooring system
      (3) Other

C. Evaluation of performance of existing and proposed current monitoring systems with respect to:
   (a) Conditions of exposure
      (1) Depth
      (2) Wind wave
      (3) Swell
      (4) Tidal
      (5) Other
   (b) Current strength
      (1) Range of measurement
      (2) Precision
   (c) Current direction
      (1) Precision

(d) Recording time
  (1) Current strength
  (2) Current direction
(e) Maintenance
  (1) Operating attention
  (2) Mechanical and/or electrical

D. Data resolution.
  (a) Manpower requirements to decode data
  (b) Estimate manpower requirements to develop current rose per meter (one depth) per month of observation

E. Cost estimate.
  (a) Basic current instrument, $/unit
  (b) Mooring station
  (c) Recording and/or transmitting and receiving components

CONDUCT OF RESEARCH AND METHODOLOGY

A significant feature of this project was an intensive library study of all facets of the current monitoring problem coupled with a personal visitation program by the contractors to oceanographic institutions and hydraulic laboratories to discuss in detail the various aspects of current measurement. These visits were of particular value in that up-to-date information was obtained on equipment under development. Furthermore, the investigators uncovered many of the limitations of various instruments that were not always evident from the publication which described the particular piece of equipment. The personal visits also were of great value in providing information on the details of procedures and costs which usually are not available in published form.

A review was made of the general character of ocean and estuarine currents and the force systems responsible for their occurrence. Current patterns were reviewed with respect to hydrodynamical relationships and expressed by means of the "path" or "Lagrangian" method and the "flow" or "Euler" method. The path method (motion through space) appears to be of major importance for design of outfall dispersion systems.

Path or drift-type measuring systems were reviewed. They included the use of surface and subsurface drogues, chemical and dye tracers, drift cards, and floats or buoys equipped for radar and sonar.

"Flow" method current systems are most frequently evaluated by current meters of various types, the most common being those employing the use of propellers, cup systems, or other rotating devices. Twenty-two different propeller-type meters and nine different cup and paddlewheel-type meters were studied in detail and evaluated insofar as possible.

The development and application of a variety of miscellaneous current meters, including stationary resistance type, geomagnetic, electromagnetic, ultrasonic, electrometric, and several potentiometric metering systems are also presented.

A thorough review of data recording and analysis systems was made. It is summarized with respect to techniques presently employed by operating agencies concerned with current data recording and analysis.

SIGNIFICANT FINDINGS

To obtain adequate data on current systems relative to the design of coastal outfall disperal systems, many days of observation are required. For example, if tidal currents are to be evaluated, a minimum of 29 days of continuous observation will be required with six months to a year of observation being preferable. Major concern should be devoted to the higher current velocities. Moreover, the path method of current measurement appears preferable although both methods may be required. While the use of drift cards and visual tracking of drogues may be adequate in many instances, the employment of radar tracking of drogues appears to have numerous advantages for extensive investigations.

Current measurement by the flow technique requires the use of a suitable instrument to record both speed and direction continuously with time. Numerous meter stations are necessary to describe adequately the current pattern, and at each station meters must be located at the bottom, mid-depth, and the surface.

Of the large number of current meters that have been developed over the years, only a few have been adapted to automatic and remote recording. The Roberts radio current meter has been used extensively in the United States for continuous current measurement with the result that most of the operational difficulties that invariably occur in a newly developed instrument have been largely eliminated. Other meters such as the Ott, Iwamiya, Dunderque, and Snodgrass meters may be suitable for continuous current measurements; however, the information on their reliability and availability in comparison with the Roberts meter is such that the Roberts meter is recommended for use at this time. Modifications recommended for the Roberts meter include: (a) separation of the speed and direction signals for ease in analysis of the record, (b) larger propeller and tail fin if velocities less than 0.3 knot are desired, and (c) provision for causing the meter to transmit information only "upon call" thereby conserving batteries and extending the period of operation between servicings. The Roberts meter should be calibrated as received from the manufacturer, for tests have shown as much as 20 percent variation in the calibration of seemingly identical meters.

The exact effect of wave action on the performance of the Roberts meter as well as other meters with rotating elements is not known and should be the subject of further investigation.

The method of chronograph recording of the output of the Roberts meter requires considerable manhours to reduce the recorded data. Some development work is now under way to feed the meter output into a recorder that will print velocity and direction on a tape, I.B.M. typewriter, or other permanent form of recording. It would be desirable if such development could be completed, as well as additional investigative effort devoted to development of high-speed computing-machine programming for the various types of correlation analyses desired.

Numerous specific recommendations are given in the report relative to physical features of current metering and recording systems. Cost data are presented for a large number of current metering systems.

FUTURE PLANS

No specific future plans exist for continuation of the recommended studies and investigations. However, the recommendations are under consideration by the Research Consulting Board.

PUBLICATIONS

1. Johnson, J. W. and R. L. Wiegel
"Investigation of Current Measurement in Estuarine and Coastal Waters," Report to State Water Pollution Control Board, 233 pages (September 1958).
2. Wiegel, R. L. and J. W. Johnson
"Ocean Currents, Measurement of Currents and Analysis of Data" Proc. First International Conference on Waste Disposal in Marine Environment, University of California, Berkeley (July 1959). In press.

CHAPTER VII

OILY SUBSTANCES ON THE BEACHES

Many of the beaches of southern California suffer the nuisance of bits of tar stranded by the waves on the sand. It has long been known that this condition is normally attributable in major part to natural oil seeps off shore, located principally west of Santa Barbara and in Santa Monica Bay. With increasing discharges of sewage and industrial wastes, and with the advent of petroleum production from artificial offshore islands, the number of sources of possible man-made pollution of the beaches is increasing. It becomes increasingly important, therefore, that water pollution control agencies have more background information about the amounts and characteristics of tarry or oily substances appearing on the beaches.

Recognizing the need for reliable methods for quantitating oily substances on beaches and background data on the concentration of such material present prior to significant off shore operations, the Western Oil and Gas Association (WOGA) were considering contracting for special studies in this area. The State Water Pollution Control Board was approached to ascertain their interest in this subject. As a result, the Research Consulting Board undertook to develop specifications for a fundamental investigation in this area which WOGA agreed to finance by direct contribution to the State WPC Board. The study and contractual arrangements were under the control of the State WPC Board.

OBJECTIVES

a. To develop methods for sampling and measuring oily substances on beaches.

b. To explore development of methods for sampling and measuring the concentration of oily substances in near-shore waters.

c. To apply methods developed in this investigation to the quantitative determination of oily substances at selected typical beaches now subject to natural oil and tar pollution.

d. To recommend a program for continued sampling and quantitation of oily substances on beaches and in near-shore waters.

CONTRACTING AGENCY, PERSONNEL, AND FUNDING

This work was undertaken under Standard Agreement WP-1 dated 1 Nov. 1957, between the State WPC Board and the University of Southern California, Engineering Center. Total reimbursement for the one-year project was $25,000. As noted, the funds were supplied by the Western Oil and Gas Association.

The project was under the direction of Professor Robert C. Merz. Mr. Ralph Stone participated in the work and served as technical consultant. Mr. James Foxworthy worked full time on the project.

RESEARCH PLAN

The project was designed to include: research of the literature and a questionnaire to find what work along lines similar to this project had been done elsewhere or was in progress; tests of devices that would collect oil from the water, including adsorptive surfaces and filters; sampling of the near-shore bottom for tarry deposits; devising of procedures for collecting representative tar-containing samples from beaches; devising of analytical procedures for determining the tar content of such samples; study of methods to determine rates of deposition of tar on the beaches; application of suitable procedures to do exploratory testing of southern California beaches; conferring and corresponding with Dr. A. A. Rosen of the Robert A. Taft Sanitary Engineering Center of U.S. Public Health Service relative to research on chemical characterization of samples of oily substances from beaches; and devising a program of monitoring the beaches in respect to oily and tarry substances. Application of sampling procedures to beaches on a broad scale had to await development of these procedures, but research on improvement and evaluation of the methods continued, and other phases of the project either ran concurrently or were done at opportune times.

METHODS AND FINDINGS

This study must be looked upon essentially as an exploration of methods. The problem of finding practical procedures for getting significant information about deposits of oily and tarry substances on the beaches is solved only by becoming familiar with these deposits and comparing different testing methods. An important accomplishment of this research is that practical procedures were determined for monitoring tar on the beaches.

The project also studied the question of amounts of oily substances in near-shore waters. The difficulties of measuring these amounts are such that no simple answer was reached. Excelsior floats showed some ability to collect oily substances touching them, but there did not appear to be very hopeful prospects of attaching quantitative significance to the results. Painted surfaces were ineffective. It was concluded that continuous pumping of the water through a filter would be necessary for quantitative recovery.

Three methods were tried for collecting and analyzing samples of tarry substances on the beaches:

a. Scraping up surface sand, along with tarry material, splitting these scrapings to a suitable sample size, and subjecting this sample to reflux extraction with chloroform.

b. Screening the scrapings to separate the tarry particles from the sand, followed by extraction of the tarry particles.

c. Hand-picking of tarry particles from the surface of the test area, followed by extraction.

It was determined that screening will separate substantially all of the tarry material. A comparison of screening with hand-picking showed an average of 90 percent recovery by hand-picking. This degree of recovery is considered adequate in view of the great variability of the amounts present on the beaches.

FINDINGS

Although this investigation was primarily concerned with development of methods, data have been obtained for the first time on the actual amounts of tar on the beaches. Also, the significance of these amounts has been qualitatively assessed. It was tentatively concluded that tar will begin to be a nuisance when the amount reaches 0.2 oz. in a 500 sq. ft. area (25 ft. along the beach by 20 ft. wide, including the line of heaviest deposition), and that it will be an occasion of complaints when it reaches 2 oz. in the 500 sq. ft. area. These amounts are approximately equivalent to averages of 1 g/m^2 and 10 g/m^2 in 50 square meter areas.

As is apparent to those who visit the beaches, the amounts of tar on the beaches from location to location and from time to time at the same location varies by several orders of magnitude. For this reason, not much significance can be attached to small differences of averages of a few results. The orders of magnitude are indicated by the following figures:

a. The highest concentrations on the beaches were found at Coal Oil Point west of Santa Barbara, where samplings on 15 days yielded amounts up to 1520 oz. per 500 sq. ft., averaging 292. The large amount here found is not surprising in view of the fact that this location received its name from the large oil seep off shore.

b. A total of 44 samplings from three areas in Santa Monica Bay yielded amounts up to 38 oz. per 500 sq. ft., averaging 4.

c. A total of 177 samples from 16 other stations located along 300 miles of coast from Hollister Ranch, 40 miles west of Santa Barbara, to Imperial Beach, near the Mexican border, gave results up to 5 oz. per 500 sq. ft., averaging 0.4. Every station showed tar on one or more visits, and every station showed zero or only a trace on one or more visits. There is, as would be expected, a tendency toward lower values at the southern end of the area. Yet even at Imperial Beach, 100 miles or more from any known oil seep, the tar may sometimes be a nuisance.

A small experiment was made with drift bottles. The results of this test, as well as work which has been done by Hancock Foundation with drift cards, show that surface drift from the vicinity of the oil seeps will undoubtedly carry some tar to beaches as far away as Imperial Beach.

A substantial part of the effort of this project was devoted to an attempt to determine the rate of accretion of tar on the beach. Two test areas in Santa Monica Bay were scraped clean of tar, including buffer strips each side of the areas actually to be sampled, and then the tar accumulated 24 hours later was determined. Fifteen such tests were made. The amounts so found were of the same magnitude as the amounts found on beaches not previously scraped. To what extent these amounts represent new deposition is uncertain. The residence time of a piece of tar on the beach in any case is not long. Incorporation of sand into the tarry pieces, with subsequent attrition and biological oxidation of dispersed particles in the sand, is believed to account for the dis-

appearance. Bottom samples in the surf zone showed no significant amounts of tar.

If the rate of deposition is of the order of magnitude indicated by the experiments, this would mean that the amount of tar coming ashore on 10 miles of Santa Monica Bay beaches probably averages somewhere between 300 and 3,000 lbs. per day.

It is a temptation to draw further conclusions, which, however, would not be supportable on statistical principles. The Contractor refrained from doing so. It is clear that many unanswered questions, such as occurrences of extremes, variations in time and space, and long-time averages, must await a sustained testing program.

A careful literature search, together with world-wide correspondence, revealed no previous work comparable to this project, although it was reported that the American Petroleum Institute has a similar project under way in Florida. Abstracts on pertinent related work are included in the report.

FUTURE PLANS

On the foundation of the work done, the Western Oil and Gas Association is having continuation studies made by a private consulting firm.

COROLLARY INVESTIGATION BY THE USPHS

Contacts were made with the Robert A. Taft Sanitary Engineering Center of the USPHS at Cincinnati, Ohio, with respect to possible research on identification of tar from beaches. Dr. A. A. Rosen made a trip to California to confer with the Executive Officer of the State WPC Board, with the research team at USC and with the Research Consulting Board. The result of the conferences was the undertaking of some identification studies by the Robert A. Taft Sanitary Engineering Center, with the objective of distinguishing the tar that arrives naturally out of the submarine seeps from that which might reach the beaches from refineries, sewage plants, and other artificial sources. In view of previous work by the Sanitary Engineering Center along this line (Anal. Chem. *27,* 790 (1955) et al.), there appeared to be no other place where studies of equal competence could be made. The results are a most welcome contribution to the technology of control of pollution of California beaches.

In the techniques that were developed, a sample of the tarry material (after being freed, if necessary, of sand or other insoluble material by chloroform extraction) is extracted with ether, leaving an ether-insoluble or asphaltene fraction; acids and bases are extracted; and the neutral fraction is then subjected to chromatographic separation on a silica column into aliphatics, aromatics, and two oxy fractions. Infrared absorption spectra were run on various fractions.

Oily or tarry substances not of petroleum origin are quite easily distinguished, both by group separation and infrared spectra. The infrared spectra do not appear to be useful in distinguishing various petroleum substances, but the group separations can be very useful.

It was found that tar collected on a beach was not materially altered in character from oil collected at a seep from which that on the beach evidently had come. In comparing seep oil with crude oil from seven

fields, there is an overlapping of percentages of the different groups, but there would be little difficulty in making a distinction between a particular crude and a specific seep oil. In general, the crudes are lower in asphaltenes and in oxy compounds than are the seep oils. The residues from straight-run and cracking distillation were similar to the crudes, except for an increase of the aromatic/aliphatic ratio upon cracking. The group characterizations of the crudes were not greatly changed by weathering for 30 days as a film on sea water.

PUBLICATIONS

State Water Pollution Control Board Publication No. 21, Part I. "Determination of the Quantity of Oily Substances on Beaches and in Nearshore Waters" by the Sanitary Engineering Research Laboratory, University of Southern California. Part II. "Characterization of Coastal Oil Pollution by Submarine Seeps", by the Robert A. Taft Sanitary Engineering Center, USPHS.

CHAPTER VIII

TRACER TECHNIQUES IN FLUSHING AND POLLUTION STUDIES OF ESTUARIES

Evaluation of the effect of waste discharge upon estuarine systems is one of the most complex technical problems confronting those concerned with water pollution abatement. The complicated nature of the problem results from physical, chemical, and biological factors associated with the *aquatic* environment combined with the known and unknown physical, chemical and biological complexities of the *marine* environment.

Because much of the water-borne waste resulting from urban and industrial development in California reaches estuarine waters, and because the amount of such wastes will increase in the future, it becomes imperative that more factual information be developed relative to the behavior of wastes in such systems. Also, increasing concern is evident about relatively slight or insidious effects of toxic wastes upon the estuarine environment. If one is to make a quantitative evaluation of the toxic effect of a given waste upon the biota, it is necessary to predict or determine both the time-concentration function of the agent with the organism of concern, and the concentration and time of contact of the toxic substance in the estuary, inasmuch as toxicity is a time-concentration phenomenon.

Water pollution control agencies are confronted frequently with resolution of the equity or responsibility of a single waste discharge amidst a complex of discharges to an estuarine system. Allocation of portions of the waste-assimilating capacity of an estuarine system to individual dischargers is necessary in the establishment of water quality objectives and waste discharge restrictions. It is obvious that there is a real need for resolution of such problems if water pollution control is to be on a rational technical basis. To date there is no satisfactory or accepted methodology for solution of such problems.

OBJECTIVES

The objective of this investigation is to develop practical methodology and techniques for field application of tracers as related to determination of flushing or exchange characteristics, waste residence time, and waste-concentration distribution in bays and estuaries generally, and specifically as related to a portion of South San Francisco Bay below Dumbarton Bridge.

CONTRACTING AGENCY, FUNDING, AND PERSONNEL

This investigation is being conducted by the Sanitary Engineering Research Laboratory, University of California, Berkeley. Mr. Robert E. Selleck is project engineer and Prof. Erman A. Pearson is faculty investigator.

Contractual support and funding in the amount of $11,050.00 was obtained from the State Water Pollution Control Board for the period March through August, 1959.

RESEARCH PLAN

A comprehensive review of estuarial hydrography, flushing, and exchange theories was conducted by the faculty investigator and project engineer for the San Francisco Bay Regional Water Pollution Control Board. These studies led to the inescapable conclusion that practical techniques were needed for evaluation of waste residence time and concentration distribution in estuarial systems.

Detailed consideration has been given to internal as well as external tracers such as dyes, chemicals, radiochemicals, and drogues. Based on economic and practical considerations, it appears that a chemical tracer, viz., dried spent sulfite liquor solids (Orzan), has the greatest potential for widespread field application.

Considerable effort was devoted to background determinations for the tracer in the area prior to tracer release.

A field scale release of Orzan as a tracer was planned for determination of tracer concentration distribution with both time and space, as well as residence time, for a portion of South San Francisco Bay.

CONDUCT OF RESEARCH AND METHODOLOGY

After considerable analytical work on tracer determination in waters of South San Francisco Bay where the suspended solids approximate 1000 mg/l, and evaluation of tracer background, decay, adsorption on silt, etc., a field-scale instantaneous tracer release was scheduled. Early in August 1959, eighteen tons of tracer (Orzan) were released near Flashing Green No. 5 south of Dumbarton Bridge. Sampling and determinations of tracer concentrations were made at representative points throughout the area and over several tidal cycles. The pattern of sampling was chosen to permit determination of eddy diffusivity and exchange coefficients, waste concentration distribution with both space and time, and the residence time of the tracer in the area.

While all analytical determinations are complete, data analysis and interpretation are still in progress.

SIGNIFICANT FINDINGS

Since field data have not yet been analyzed or interpreted, no specific conclusions can be announced at this time. However, some general qualitative observations can be made relative to field tracer methodology.

1. Orzan or dried spent sulfite liquor appears to be an economic and practical tracer for pollution investigations. However, before a release is made in relatively turbid or polluted waters, investigation of tracer background and interference should be made. In poor quality waters it may be necessary to evaluate adsorption and decay characteristics of the tracer in the area.
2. Orzan can be conveniently handled in large quantities, it goes into solution readily, and it can be determined with adequate precision at concentrations as low as 0.1 mg per liter even in turbid and waste-bearing waters.

3. Tracer releases are not practicable for "one-shot" studies of an entire large estuary, because of the quantity and cost of tracer required. Nevertheless, Orzan appears to be a satisfactory and practical tracer for following a waste over the first few tidal cycles in proximity to the discharge point. In general, this geographical area is a region of major import and critical effects as related to waste discharge.

FUTURE PLANS

Current plans for the future are limited to analysis and interpretation of the field data obtained with the prototype tracer release in accordance with several mathematical models of estuarial exchange mechanisms. A final report covering the overall tracer studies is scheduled for release in 1960.

PUBLICATIONS

The faculty investigator has presented a technical paper in this general subject area which provided, in part, a basis for the present study.

1. "Tracer Methodology and Pollution Evaluation of Estuaries." Proceedings of First International Conference on Waste Disposal in the Marine Environment, July 22-25, 1959, University of California, Berkeley (In Press).

CHAPTER IX

ENGINEERING EVALUATION AND DEVELOPMENT OF BIOASSAY METHODS

Toxic materials or wastes discharged to the marine environment may have an adverse effect on the biota. The magnitude of the effect depends on the concentration of toxic agent, the time of contact, and the type of flora and fauna present. Estimation of the "safe" concentration of toxic material in the aquatic environment at the most advanced practical level has been based generally upon short-term bioassays with the major economic form, i.e., fish. Bioassays are conducted at varying concentrations of toxic agent, from which the concentration or lethal dose (LD) that kills 50 per cent of the test organisms in 48 hours (48-hour MLD also called 48-hour TL_m or LD_{50}) is determined. The so-called "safe" long-term concentration is assumed to be about one-tenth of the 48-hour median lethal dose. A more complete and reliable, yet realistic, bioassay procedure is needed to predict the possible effect that a given waste material may have on the marine environment.

OBJECTIVE

The objectives of this investigation are to evaluate, refine, and/or develop bioassay techniques and methodology for assessing practically the potential effect of toxic materials on the marine environment.

CONTRACTING AGENCY, FUNDING, AND PERSONNEL

The investigation is a part of the activity of the Sanitary Engineering Research Laboratory of the University of California, Berkeley. This project was initiated as a PhD thesis investigation by John W. Klock, with Prof. E. A. Pearson as Faculty Investigator, and was financially supported in part by the Sanitary Engineering Research Laboratory. Contractual support and funding in the amount of $4,500 was obtained from the State Water Pollution Control Board during the period April through June, 1959. This funding made possible considerable expansion and acceleration of the original research program.

RESEARCH PLAN

As originally conceived, the research plan proposed an evaluation, with practical laboratory bioassay methods, of the susceptibility or response of typical significant marine forms to several toxic substances such as copper, mercury, phenol, and possibly one or two complex industrial wastes. The assay procedures utilized rate measurements of selected body functions of a group of animals chosen for their importance in intermediate biodynamics, economic fisheries, and diversity of phylogenetic and ecological types. The organisms evaluated in simultaneous bioassay studies for each of toxic agents are:

1. Polychaete: *Merceirella enigmatica* (tubeworm)
2. Mollusk: *Mytilus edulis* (mussel)
3. Crustacean: *Neosphaeroma oregonensis* (isopod)
4. Fish: *Gasterosteus aculeatus* (3-spined stickleback)

CONDUCT OF RESEARCH AND METHODOLOGY

The test organisms were exposed to varying concentrations of toxic agent for periods of time up to 96 hours and the short-term responses of the organisms were observed. The most readily induced, significant functional response was employed for each organism. Based on metabolic importance and ease of observation, pumping and ventilation rates appear to be the best parameters. For the appropriate organisms these criteria are as follows:

1. Mussel—pumping rate
2. Annelid—clearance rate
3. Crustacean—pleopodal ventilation rate
4. Fish—opercular movement rate and mortality

The response of the organisms exposed to the toxic agent was evaluated for these phenomena and compared to those of the controls. For example, the pumping rate of a group of mussels exposed to the agent was periodically observed by quantitative evaluation of the rate of clearance of a natural clay suspension, and these rates were compared to that of the control group. Similar methodology was employed for the response of the annelids; that is, clearance rates of natural clay suspensions were evaluated for the test organisms and compared to that of a control group.

The response of the crustacean was evaluated in a slightly different manner. The response was quantitated by observation of the rate of mixing of a clear solution with a clay colloidal suspension, the two fluids being in a battery jar separated by a partition holding a large number of small glass tubes hydraulically connecting the two fluids, each tube containing an organism. The rate of mixing of the two fluids, for a given physical system, is a function of induced flow or mixing of the two fluids resulting from the organism's pleopod movement which is a measure of its ventilation rate.

The rate of opercular movement of the fish, 3-spined stickleback, is the body function observed. In addition, for comparative purposes, conventional mortality bioassays were conducted to determine the 48-hour MLD for each agent under test conditions.

In all cases, except for mortality assays of the stickleback, the response of the organism exposed to the agent was compared relative to that of the control group, and normalized with respect to the relative response of the two groups at time zero.

Figure 11 shows a photograph of the bioassay facilities including the assay aquaria for fish, mussels, annelids, and crustaceans.

SIGNIFICANT FINDINGS

Suitable techniques have been developed for laboratory evaluation of body function response of annelids and crustacea to toxic agents. Also, previously developed systems for evaluation of body function response

for mussels and fish have been tested and adapted for use in these studies.

It is premature to draw any definite conclusions from the studies completed to date. The results of experimental assays have not yet been studied intensively, analyzed statistically, or interpreted. Figure 12 shows a somewhat typical set of response characteristics obtained for the mussel, *Mytilus edulis,* for varying concentrations and exposures to copper.

Some preliminary qualitative observations based on test results appear to be as follows:

1. Physiological indices of body functions of several animals are more critical measures of the effect of toxic agents in the marine environment than are standard mortality studies performed on various species of fish.
2. The relative sensitivity to toxic materials of one species compared to another is not consistent, but is found to vary with materials tested and biologic types.
3. Comparison of the concentration of toxic agent producing the first "apparent" significant live response with the "presumably safe concentration" $\frac{\text{(48-hr MLD, ORSANCO 1955)}}{10}$ indicates a very poor correlation.

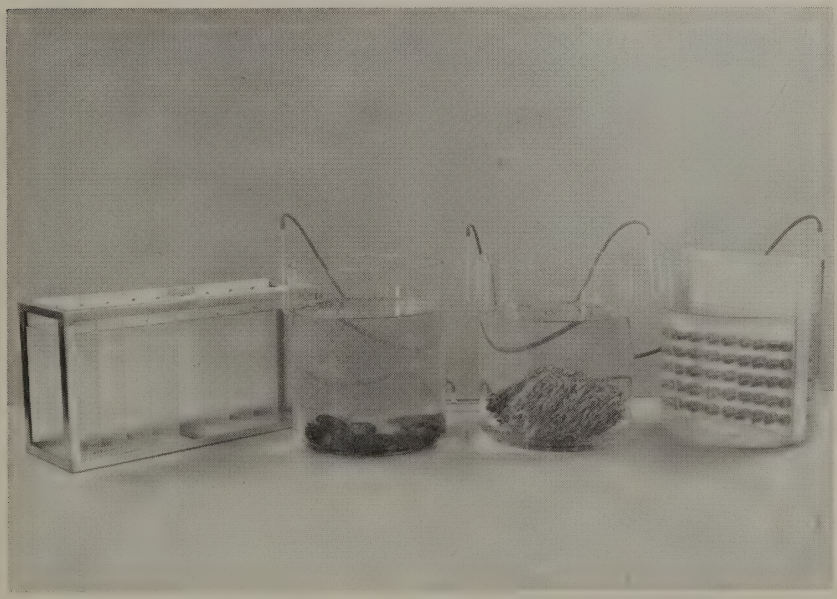


Figure 11

BIOASSAY FACILITIES FOR FISH, MUSSELS, ANNELIDS AND CRUSTACEANS

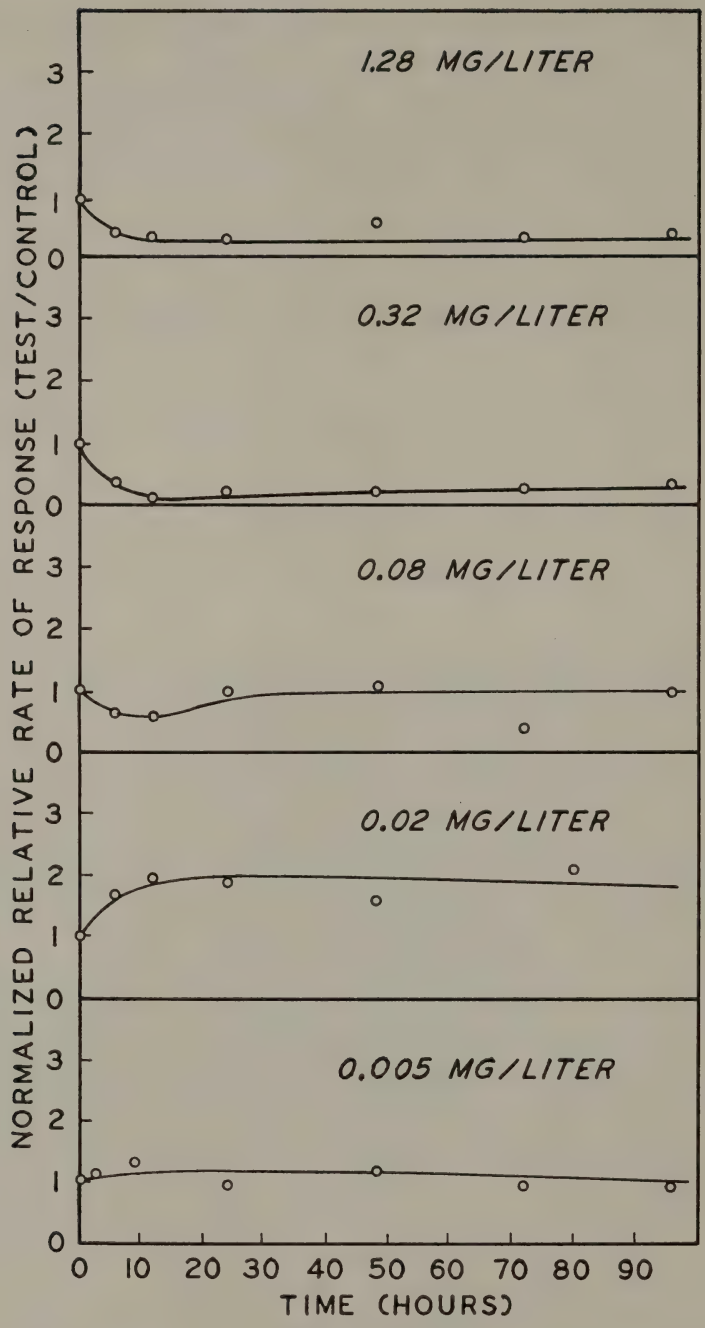


Figure 12

RESPONSE OF MUSSEL *MYTILUS EDULIS* TO COPPER

Agent: $CuSO_4$ expressed as Cu.

FUTURE PLANS

One of the recommendations of the present study is to continue the investigation through 1959-60 to include additional toxic agents, wastes, and environmental factors in the bioassay evaluation program. Standard Service Agreement No. 12-15 dated September 1, 1959, between the State Water Pollution Control Board and the University of California, authorizes continuation of the present research program through June 30, 1960.

PUBLICATIONS

1. Interim Report, *Engineering Evaluation and Development of Bioassay Methods* to California State Water Pollution Control Board, dated 30 September 1959, 53 pages (typed).

CHAPTER X

GUIDELINES FOR FURTHER RESEARCH

PERSPECTIVES

At this point, approximately midway through the research program on marine waste disposal, it is well to look at the program in its entire perspective, to review and reassess the orginal aims and purposes, to evaluate the progress to date, and to determine the major research needs that are most urgent and how they can best be accomplished. By its very nature, research does not lend itself to clear-cut, long-range planning without frequent revisions and realignment on the basis of the data obtained to date. For this reason, it is essential that the program be reviewed and reoriented from time to time in order to achieve the maximum benefit from the funds expended.

PROGRESS TO DATE

The submarine outfall research program has been underway since November 1956, with a total of seven research projects. The major project, in terms of funding and personnel, involving an oceanographic survey of the continental shelf area of southern California, should be completed by 30 June 1960, insofar as sampling and analysis are concerned. Another year will be required for completion of all of the analyses and interpretation of the data and a preparation of the final report. Consequently, by June 1961, this project will be terminated. The other project dealing with oceanographic analysis of the continental shelf area, at Humboldt State College, started later than the one at the Hancock Foundation, and consequently will probably not be completed until June 1962.

The project on the effect of waste discharges on kelp, at the Scripps Institution of Oceanography, was originally intended for a total of four years; consequently, it should be terminated about June 1961.

The other four projects that have been undertaken to date, namely the study of ocean current meters, the quantitation of oily substances on beaches and near-shore waters, the development of tracer techniques in flushing and pollution studies of estuaries, and the engineering evaluation and development of bioassay methods, have been completed to the extent of the original project scope. Each project, however, contained many aspects that are worthy of further research if funds become available.

The intensity and scope of the work accomplished to date are a reflection of the availability of funds, the research areas deemed most urgent, and the availability of research personnel and equipment ready to undertake these specific projects. With the major project drawing to an end within the next year or so, it is anticipated that funds will be available for a shift in emphasis to some of the research needs that have had to be postponed temporarily. The period from July 1961 to June 1962 should represent a time of significant reorientation of the

research effort, to undertake new fields of endeavor for many aspects of waste disposal in addition to those related to the submarine outfall discharge of sewage.

MAJOR RESEARCH NEEDS

As indicated in the introduction of this report, Dr. Erman A. Pearson submitted in December 1955, as part of his report on "An Investigation of the Efficacy of Submarine Outfall Disposal of Sewage and Sludge" a list of eight recommendations for additional research. As an outgrowth of these recommendations, the research consulting board recommended the specific objectives listed on the first page of Chapter II of this report. Many of these research needs have not been resolved to date, and indeed several of them have not been undertaken by research projects under the sponsorship of the State Water Pollution Control Board.

In the opinion of this board, one important aspect of the marine disposal of sewage and other waste waters deals with the resolution of the circulation system and water mass movement in near-shore and estuarine waters. For this purpose, it is especially important to develop methodology and equipment for adequate monitoring of this circulation system, to determine the pattern of dispersion, dilution, and transport of wastes. Corollary to this project is an analysis of the fundamentals of mixing and dispersion of wastes in the receiving waters. These projects should be undertaken as soon as possible, and especially as soon as a research contractor can submit a project proposal outlining the methods of attack.

In the field of microbiology and epidemiology attention should be directed particularly to the public-health significance and viability of enteric organisms in seawater, including the reaction kinetics, effects of adsorption and sedimentation, and the significance of various indicators of contamination in pollution. Emphasis should be directed to viruses, protozoan pathogens, and fecal streptococci, as well as the conventional indicator of human contamination, *Escherischia coli*. Far too little is known about the behavior of these organisms in seawater, their viability following various types of treatment (especially chlorination), and their removal by various physical and biological mechanisms in the ocean.

Aside from these two major areas of research needs in the marine disposal of waste waters, it might be well to reorient the research efforts of the State Water Pollution Control Board to other methods of disposal including land disposal and the percolation of wastes through soil. As a further indication of the type and scope of work that has been suggested for further research programs, the following list has been compiled from written and oral recommendations presented at the Session on Research Planning conducted by the research consulting board on 29 May 1959 in Los Angeles. No priority has been assigned to these recommendations, nor does listing here constitute concurrence in or endorsement by the RCB or the State WPC Board.

a. Evaluation of the influence of variables such as particle size, suspended solids load, settling rate, type of material, surface covering of percolation area, and subsurface conditions on infiltration rates of waste waters.

b. Further work on quantitation of oil on beaches and in near-shore waters.

c. Studies of the dispersion and/or diffusion of pollutional substances in ground water.

d. Development of better analytical procedures for determination of trace amounts of syndets and surfactants in surface and ground waters. Also, criteria for syndets in water for various beneficial uses, especially human consumption.

e. Development of techniques for determining the origin of debris and other floating material on the ocean surface or at the shoreline, to determine if it originates from outfalls or from other sources.

f. Determination of isolines for floral and faunal populations near ocean outfalls.

g. More accurate and rapid determination of the strength and extent of sewage fields near outfalls, utilizing molecular filter techniques and exotic bacteria.

h. Evaluation of monitoring procedures and techniques.

i. Determination of grasses and crops that can be grown most successfully under conditions of sewage irrigation, and related factors such as percolation and evaporation rates, mosquito problems, types of distribution and drainage systems.

j. Characterization of ocean sludge deposits, their effects on the area, and their rates of decomposition.

k. Studies on the distribution of fresh water wastes at the ocean shoreline.

l. Development of criteria for the use of various types of effluent for various agricultural crops.

m. Study of coliform die-off in oxidation or holding ponds.

n. Development of investigative techniques and methods to determine the effect of waste discharges on marine fauna and flora. Preparation of "Standard Methods" for ocean sampling.

o. Investigation of the degradation of unstable pollutants such as phenol, cyanide, sulfites, etc., in surface and ground waters.

p. Revision of WATER QUALITY CRITERIA.

q. Investigation and quantitation of CO_2 generation in sanitary landfills as related to ground water pollution.

r. Study of the occurrence of tumors or parasites in fish near ocean outfalls, and make census of such fish.

s. Intensive study of areas close to existing outfalls.

t. Investigation of sedimentation patterns around outfalls.

u. Study of effects of return irrigation water on water quality.

v. Research on methods of disposal of cannery wastes.

w. Expansion of bioassay development.

RECOMMENDATIONS

In developing the research program for the next three to five years, it is recommended that the State Water Pollution Control Board give

priority to the following projects, but not necessarily in the order listed:

1. Completion of the projects already underway. Current projects will probably be finished in the 1961-1962 period.

2. Resolution of the circulation system and water mass movement in near-shore and estuarine waters, with special attention to the development of methodology and equipment for adequate monitoring of this circulation system.

3. Determination of the public-health significance and viability of enteric pathogens (viruses, bacteria, protozoa, and higher forms) in seawater, including reaction, kinetics, effects of adsorption and sedimentation, predation, and similar phenomena.

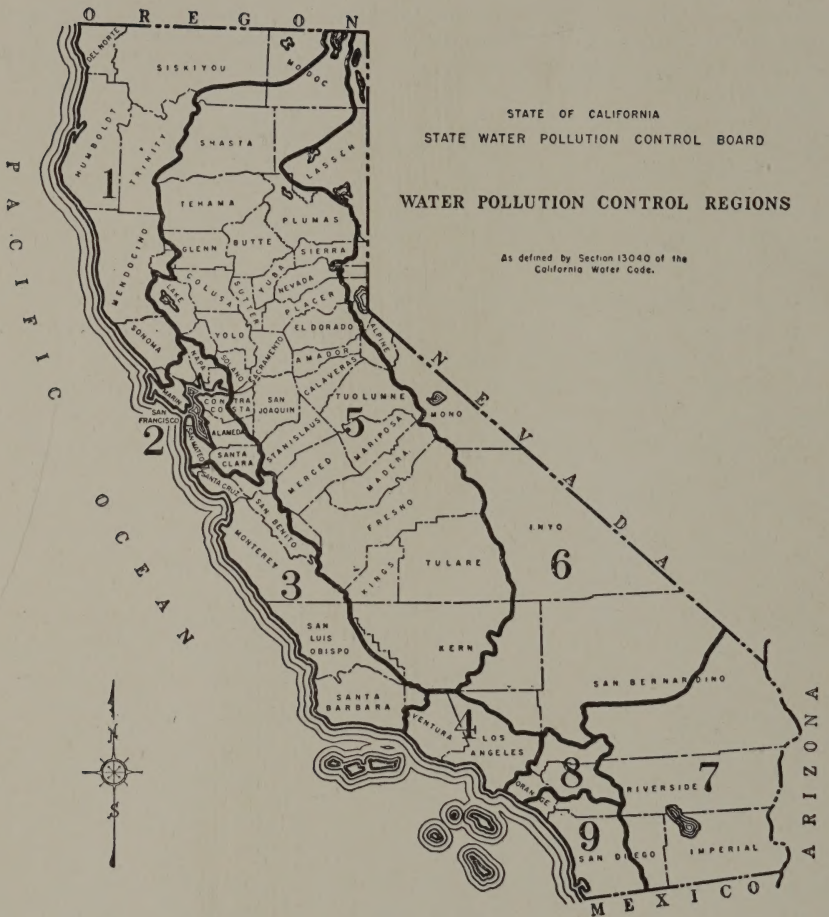
4. Development of suitable methodology for quantitating oil and surface films on water.

5. Revision of SWPCB Publication No. 3 "Water Quality Criteria."

6. Collation, and evaluation of oceanographic data being accumulated by numerous agencies in California.

7. Studies of groundwater pollution as a result of refuse dumps, waste-water percolation, and recharging through injection wells.

8. Further investigation into methods of waste-water reclamation and reutilization.



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